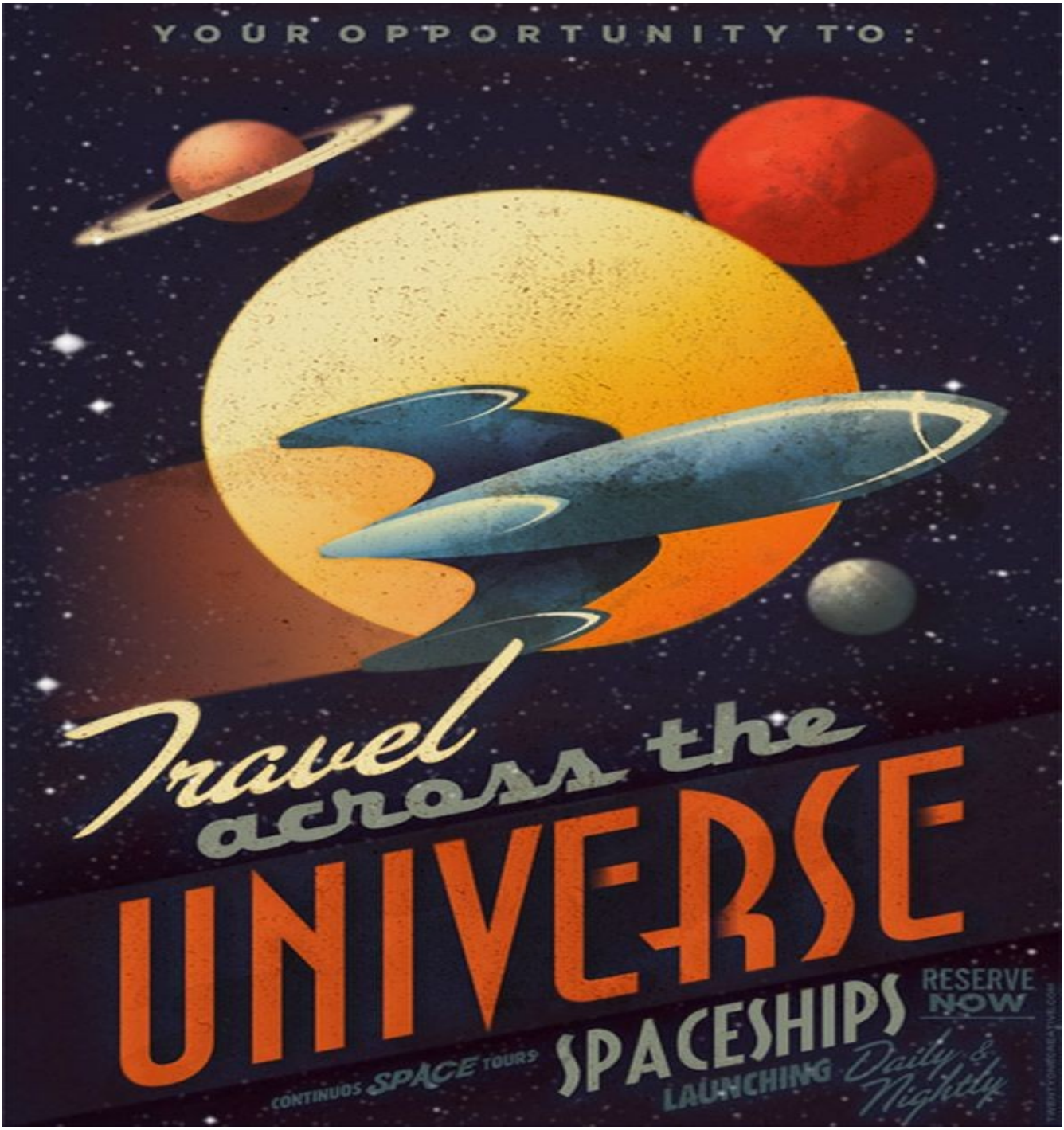
SPACE
TRAVEL

Thoughts on Space Travel

By John V. Peters (November 28, 2025)



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Human Space-faring Prospects Based on Current Scientific Knowledge

Introduction

The universe is so ordered that different technological civilizations, should they arise on different planets circling different stars in this or other galaxies, cannot physically visit one another. Nor can they establish any reasonable two-way communications.

Our nearest neighbor star is Proxima Centauri, a red dwarf located 4.2 light years away with a planet circling it in the habitable zone. At the average speed of Apollo 11 traveling to the moon in 1969, 3500 miles per hour, a trip to our nearest star would take 805,480 years. The calculation is 4.2 light years x 5.88 x 10^12 miles per light year/3,500 mph = 7.056 x 10^9 hours. Divide this by 24 hours x 365 days = 805,480 years. Even if we could increase our speed by 1,000 times, to 0.0052 light speed (3,500,000 mph), the trip would take more than 805 years one way.

If a technological civilization happens to exist on Proxima Centauri's planet at this moment, it would take our communications 4.2 years to travel to them at light speed and another 4.2 years for their response to reach us. And this is the best-case scenario for communicating with a civilization outside our solar system, since this is our nearest stellar neighbor. So far, we haven't received any communications from Proxima Centauri b or any other interstellar source.

Conceivably, more distant civilizations might pick up our radio and television signals many years, perhaps millions of years, after they began traveling out from earth at light speed. By the time these signals are received, however, human civilization will probably no longer exist. And any return signals sent by another civilization might arrive long after humans and perhaps earth itself has passed out of existence.

By the same token, we have nothing to fear from any other technological life forms within our galaxy or in our universe. They too evolved in unique circumstances of place and time and biology, and they are just as restricted as we from traveling very far off their home planet. Physically, they can never reach us and we can never reach them. We could conceivably pick up messages from their civilizations sent long ago, just as they may receive radio and television programs that we broadcast into space. But we couldn't establish two-way communications.

Diverse civilizations in our galaxy or our universe will never be able to communicate back and forth, let alone visit one another. The great expanse of distance and time and the limit of the speed of light will not permit it.

It is hard to see how any life form could evolve anywhere with a long enough lifetime and with a hardy enough biological and psychological constitution to allow for interstellar space travel.

You might call this the no-contact law of the universe.

A: General Review of the Math of Rockets

Brief Summary of Early Space Activity

The Soviet Union sent the first satellite, Sputnik 1 into temporary earth orbit on October 4, 1957, prompting the United States Congress to approve massive funding for scientific education. The United States sent a satellite into temporary orbit on January 31, 1958. The Soviet Union sent Luna 3 to circle the moon and photograph the back side in October 1959. And the Soviet Union sent the first man into earth orbit on April 12, 1961. The United States did the same on February 20, 1962. These events prompted U.S. President Kennedy to announce a goal of landing men on the moon and returning them to earth by 1970 and Congress began appropriating huge sums of money to accomplish this goal.

The U.S. launched the first uncrewed ship to the moon, Apollo 4, on November 9, 1967, followed by similar uncrewed ships, Apollo

5 (January 22, 1968) and Apollo 6 (April 4, 1968). The first 3-man crewed ship to travel to the moon, circle the moon, and return to earth was Apollo 8 (December 21-27, 1968). Finally, on July 16, 1969 Apollo 11 was launched with a 3-man crew toward the moon. Two of the three men landed and walked on the moon on July 20, 1969, spending 21 hours on the moon's surface before returning to orbit, transferring to the command module and returning to earth. Apollo 17, launched December 7, 1972 was the last manned flight to and landing on the moon.

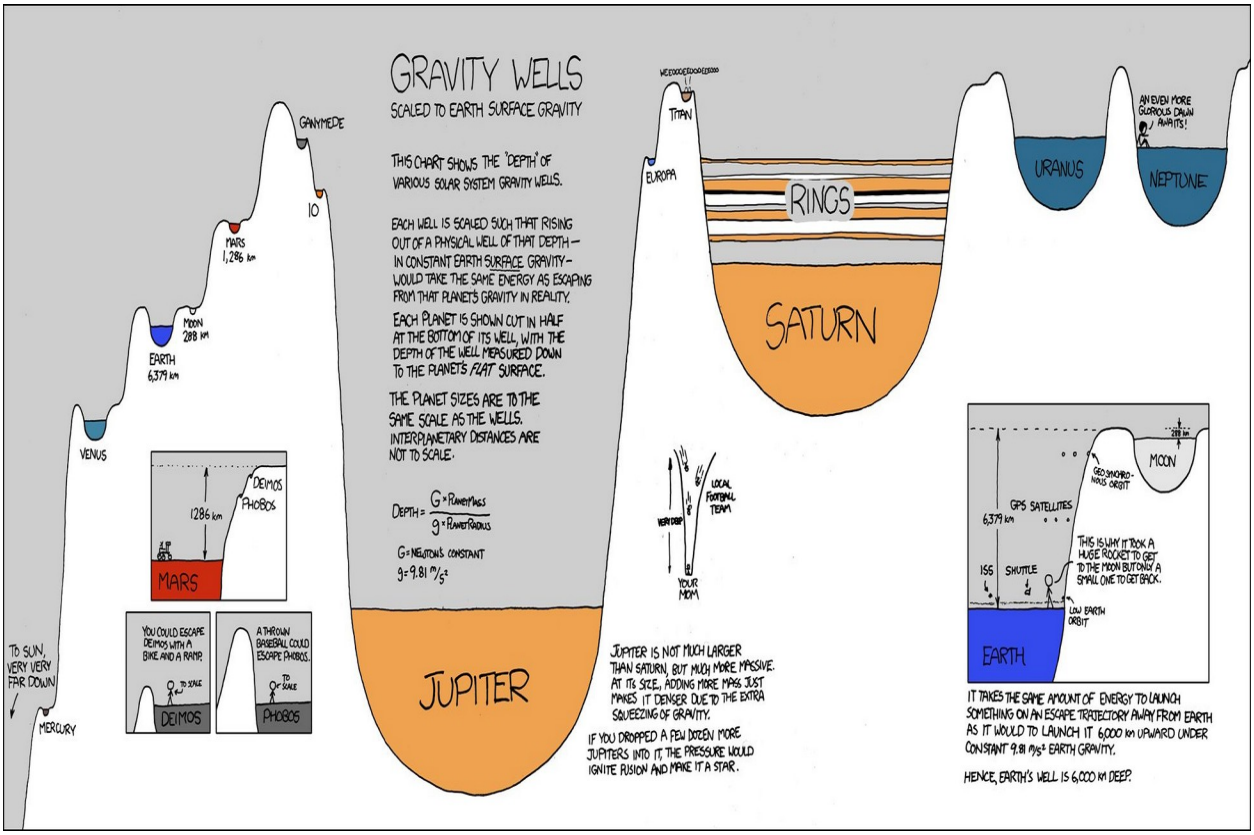
The Soviet Union had begun its N1 program in 1959 aimed at sending men to the moon. However, development problems, rocket test failures and administrative conflicts led to the program's cancellation in 1974. The N1 was a five-stage rocket with a first-stage booster producing 45,400,000 Newtons of thrust compared to the U.S. Saturn V rocket's 33,400,000 Newtons of thrust. Not until the SpaceX Starship launched on April 20, 2023 would a first stage rocket thrust exceed the N1 record.

Astronauts have not traveled beyond low earth orbit since 1972. The International Space Station was launched into orbit around earth on November 20, 1998, and has been in use ever since. It resides about 250 miles above earth where it travels at about 17,000 mph and circles the earth in just over 90 minutes. Long-term occupancy began on November 2, 2000. The ISS is expected to remain operational until the end of 2030. A 2011 U.S. law known as the Wolf Amendment effectively excluded the Chinese from participating in the ISS by forbidding the U.S. to participate with the Chinese. This might be thought of as a second Chinese Exclusion Act analogous to the one passed in 1882 to exclude Chinese people from the United States, only rescinded in 1943 to gain Chinese cooperation in World War II.

This exclusion led to the launch in 2021 of the Chinese Tiangong space station (Sky Palace), a modular structure about one-third the size of the ISS. It is currently occupied permanently by three astronauts, with a capacity of six, and is in a similar orbit height as the ISS. The Tiangong involved the cooperation of Russia,

France, Sweden and Italy. Seventeen countries are participating in space experiments with Tiangong and negotiations are underway for the participation of astronauts from other countries. Officials have stated that the future participation of foreign astronauts will be guaranteed.

Getting Off the Earth


GRAVITY WELLS
SCALED TO EARTH SURFACE GRAVITY
THIS CHART SHOWS THE "DEPTH" OF VARIOUS SOLAR SYSTEM GRAVITY WELLS.
EACH WELL IS SCALED SUCH THAT RISING OUT OF A PHYSICAL WELL OF THAT DEPTH — IN CONSTANT EARTH SURFACE GRAVITY — WOULD TAKE THE SAME ENERGY AS ESCAPING FROM THAT PLANET'S GRAVITY IN REALITY.
EACH PLANET IS SHOWN CUT IN HALF AT THE BOTTOM OF ITS WELL, WITH THE DEPTH OF THE WELL MEASURED DOWN TO THE PLANET'S FLAT SURFACE.
THE PLANET SIZES ARE TO THE SAME SCALE AS THE WELLS. INTERPLANETARY DISTANCES ARE NOT TO SCALE.
DEPTH = G×PLANETMASS / 9×PLANETRADIUS
G=NEWTON'S CONSTANT
9=9.81 m/s²
TO SUN, VERY VERY FAR DOWN
MERCURY
VENUS
EARTH 6,379 km
MOON 288 km
MARS 1,286 km
GANYMEDE
10
1286 km
DEIMOS
PHOBOS
MARS
YOU COULD ESCAPE DEIMOS WITH A BIKE AND A RAMP.
TO SCALE
DEIMOS
A THROWN BASEBALL COULD ESCAPE PHOBOS.
TO SCALE
PHOBOS
JUPITER
JUPITER IS NOT MUCH LARGER THAN SATURN, BUT MUCH MORE MASSIVE. AT ITS SIZE, ADDING MORE MASS JUST MAKES IT DENSER DUE TO THE EXTRA SQUEEZING OF GRAVITY.
IF YOU DROPPED A FEW DOZEN MORE JUPITERS INTO IT, THE PRESSURE WOULD IGNITE FUSION AND MAKE IT A STAR.
WE EXCEEDED 10,000 EFFING KM
TITAN
EUROPA
RINGS
SATURN
URANUS
AN EVEN MORE GLORIOUS DAWN AWAITS!
NEPTUNE
VERY DEEP
LOCAL FOOTBALL TEAM
YOUR MOM
MOON
GEOSYNCHRONOUS ORBIT
GPS SATELLITES
6,379 km
ISS
SHUTTLE
THIS IS WHY IT TOOK A HUGE ROCKET TO GET TO THE MOON BUT ONLY A SMALL ONE TO GET BACK.
LOW EARTH ORBIT
EARTH
IT TAKES THE SAME AMOUNT OF ENERGY TO LAUNCH SOMETHING ON AN ESCAPE TRAJECTORY AWAY FROM EARTH AS IT WOULD TO LAUNCH IT 6,000 km UPWARD UNDER CONSTANT 9.81 m/s² EARTH GRAVITY.
HENCE, EARTH'S WELL IS 6,000 km DEEP.

The first problem of engaging in space travel is to get off the earth. Gravity is the problem. On earth gravity exerts a pull toward the center of the planet with an acceleration force of 9.8 meters per second per second. Any material object leaving earth must overcome the force of earth's gravity. The velocity needed to escape earth and not fall back again is defined by the equation:

$V_e = \sqrt{2\,GM/r}$

Where V_e = the escape velocity in meters per second

G = the gravitational constant 6.67 x 10^-11, the empirical value of the force experienced between two 1kg masses one meter distant from one another

M = mass of the earth, in kilograms, 5.97 x 10^24 kg

r = the radius of the earth, 6,371,000 meters

g = GM/r^2, the acceleration exerted by earth's gravity, 9.81 meters per second squared. Consequently, the mass of the earth M = (g x r^2)/G.

The escape velocity from earth is 11,180 m/sec or about 11.2 km/sec, equal to 40,248 km/hr. Dividing by 1.609 gives us 25,014 mph.

If you want to get into a parking orbit around earth at 241 km (150 miles) above the planet, we can use the formula $\sqrt{GM/(r+h)}$, where r = the radius of the earth and h = the height above the surface of earth. The velocity required is 7,764 meters per second or 27,951 km/hr. And this equals 17,372 mph.

The orbit period in hours is equal to T = [2 x pi x (r+h)]/v = 2 x 3.14 x 6,612,000/27,951 = 1.49 hours or 60 x 1.49 = 89 minutes.

With gravity slightly lower at a height of 150 miles, escape velocity from this orbit around the earth is about 10,133 meters per second, which computes to be 36,478 km/h or 22,671 mph. The formula is $V_e = \sqrt{2\,GM/(r+h)}$.

The gravity of the gas giant Jupiter is 2.5 times that of earth. It would be far greater if Jupiter were a solid planet like earth.

A Note On Calculations and Units

Physicist Richard Feynman wrote in Tips On Physics (2006), page 82:

Remember: Whenever you're stuck in a mathematical analysis, you can always do it by arithmetic.

Using numbers allows me to verify and check my calculations and catch mistakes. And it allows you, the reader, to do the same.

The only way to be sure our results are accurate is to keep track of the units of our calculations as well as the numbers being used, and this is also the only way my work can be checked by you or anyone else. So, I include the units in many of my calculations to be sure of myself and to allow readers to see what is being calculated. For example, when you divide meters per second (m/s) by seconds (s) the result is meters (m), since ms/s = m.

To illustrate further, let's look at the units involved in the formula for escape velocity from the earth, $V_e=\sqrt{2\,GM/r}$. We will ignore the numbers (2, 6.67,5.97, and 6,371,000) since we are only interested in the units. Let's start with G, which is defined as Nm^2/kg^2. N stands for Newtons of force and is equal to Kg x m/s^2 or kilograms times meters per second squared. This represents mass (kg) times acceleration (m/s^2). So, therefore, G = kg x m/s^2 x m^2/kg^2. We want to combine or cancel common terms, but this equation may be confusing, with its positive and negative exponents. This is a case where it helps to put the equation of units into an exponential form involving only multiplication. This yields G = kg^1 x m^1 x s^-2 x m^2 x kg^-2, where we use a minus exponent for each division term. Now we can just add the exponents of common terms together to get our result and G = kg^-1 x m^3 x s^-2. The other two terms in the equation are simply M = kg^1 and r = m^-1 since it involves division. So, $V_e=\sqrt{2\,GM/r}$ = square root of 2 x kg^-1 x m^3 x s^-2 x kg^1 x m^-1 = square root of 2 x m^2 x s^-2 = square root of

2 x m^2/s^2 = 1.41 x m/s and the units of the escape velocity are meters per second, as we would expect.

A Brief Note On Force

What force does it take to achieve the speeds necessary to achieve a parking orbit around or escape velocity from earth?

In the metric system, force is measured in Newtons. A Newton of force is required to accelerate a one kilogram object at the rate of one meter per second squared. An object's mass in kg x 9.8 equals the Newtons of force earth's gravity is exerting on the object at earth's surface. Before an object can rise off the ground it must first counter this force.

To compute the thrust force of a rocket we multiply the rocket's mass flow rate in kilograms per second by the exhaust velocity in meters per second. The mass flow rate is the flow of fuel in kg/s and the exhaust velocity is the speed of the rocket exhaust gases in m/s. Multiplied together this gives kg m/s^2 or Newtons, which also equals mass (kg) times acceleration (m/s^2).

Sometimes rocket specifications give only the thrust and the exhaust velocity. If so, we can divide the thrust by the exhaust velocity to obtain the mass flow rate in kg/s. In this paper I will designate the thrust force as F, the mass burn rate or fuel use rate as R, and the exhaust velocity as Ve. Ve for exhaust velocity is not to be confused with Ve for escape velocity discussed earlier; sometimes symbols have to do double duty, and Ve is commonly used for exhaust velocity. Force is in units of Newtons, the mass burn rate is in kg/s and the exhaust velocity is in m/s.

For the gravitational force on an object on earth we multiple the weight in kilograms by the known gravitational or acceleration force of 9.8 m/s^2. A rocket's weight in kilograms is multiplied by 9.8 m/s^2 to get the Newtons of force that the earth is exerting on the rocket; the propulsion system of the rocket must overcome this force and apply more force to counter the inertia of the mass of the rocket before it will rise into the sky.

Thrust to Weight Ratios

Thrust to weight ratios involve a comparison where both terms are expressed in Newtons. Weight is converted to Newtons of force by multiplying by the gravity involved, 9.8 in the case of earth gravity at sea level.

A thrust to weight ratio of 1.0 means that a rocket will not lift off of the ground.

The excess thrust over and above weight (in Newtons) divided by the weight (in kilograms) gives the acceleration at liftoff. For example, if the excess Newtons are 5,000,000 and the weight of the rocket is 3,000,000 kilograms, then the acceleration at liftoff is 5/3 = 1.66 meters per second per second. Dividing this by earth gravity at sea level gives 1.66/9.8 = .169 or 16.9% of earth gravity, much less than one g where earth gravity at sea level equals one g.

Some typical thrust to weight ratios, with both terms expressed in Newtons, for the First Stage of multi-stage rockets seeking to place their payload into earth orbit are:

First-stage Saturn V (Apollo) rocket	1.165 (gravity is 9.8 m/x^2)
First-stage Falcon 9 rocket	1.413
First-stage Space Shuttle rocket	1.420
Any theoretical one-stage rocket	1.500 or more
The Apollo lunar lander rocket	1.811 (gravity is 1.6 m/s^2)
The Apollo lunar ascent rocket	2.019

Recoil Propulsion and the Rocket Equation

In the vacuum of space with negligible gravitational influences from bodies of matter the only force available for movement is

the recoil force. This means throwing away part of your spacecraft, usually in the form of ignited fuel and directed exhaust. The equation p=mv allows us to calculate the momentum generated by the exhausted mass of fuel, where p = momentum, m = mass, and v = velocity. Momentum equals mass times exhaust velocity. And since momentum is a conserved quantity there must be an equal momentum in the opposite direction. In the vacuum there is no friction to affect the ship's forward momentum caused by the backward exhaust of gases. Once you attain the speed you want, you can shut off your engine and just continue to coast at the same speed.

We can then turn the momentum equation around to v=p/m and calculate the velocity of the spacecraft generated by the rocket's exhaust momentum divided by the ship's mass.

If we want the spacecraft to achieve some specific velocity we can use the Rocket Equation, first derived by the Polish/Russian high school math teacher Konstantin Tsiolkovsky in 1897:

$$M_i \,/\, M_f = e^{\left(\frac{V_{goal}}{V_{exhaust}}\right)} = 10^{0.4343\,¿¿}$$

Where m_0 is the mass of the spacecraft and its expendable fuel, m is the mass of the permanent spacecraft, e=2.718, V_{goal} is the velocity goal of the spacecraft and $V_{exhaust}$ is the velocity of the exhaust gases. The result tells us that to achieve our velocity goal we need a mass of fuel that is a multiple of the permanent spacecraft.

Ten raised to a power may be more familiar to most of us, so I have included this in the equation. The equation is e^n = 10^(n x ln 10) = 10^n(0.4343). In the equation above, n = Vgoal/Vexhaust.

Professor E. M Purcell of Harvard University wrote an article "Space Travel: Problems of Physics and Engineering" (1962) in which he says:

Only by throwing out a part of its own mass can a vehicle achieve recoil forces to change its own velocity—or at least the velocity of the part of it that remains intact.

A rocket is a recoil device of this type...whether it is run by chemical power, nuclear power, or any other source of power.

...the mass remaining in the space ship gets smaller all the time....

If the payload is to travel 4.2 light years [the distance to our nearest star Proxima Centauri] *during 100 years, its speed must be 0.042 times the speed of light.*

Using twice the 1962 standard exhaust velocity of 2.5 kilometers per second, that is, using 5 km/sec, Purcell calculates that the mass of the fuel must be 10^1094 greater than the crewed spacecraft itself. This, as Purcell says, is an impossibly large number.

Changing the time allowed for the trip to 5,000 years it would still require a fuel mass of 8 X 10^21 times the mass of the crewed spacecraft. As he points out, the mass of the entire earth is only 6 X 10^21 tons.

We would have to increase the travel time to 62,000 years in order to reach the efficiency of the Apollo 11 flight to the moon in 1969. Apollo 11 required 64 times the mass of the payload sent to the moon. Of course, this is fuel just to get to Proxima Centauri. We would have no fuel left to decelerate to a stop and would just keep on going with no hope of returning to earth.

The problem of carrying enough fuel for constant acceleration in space is very limiting, let alone having enough fuel to come to a stop at some destination or to return to earth and stop again when reaching earth.

The Rocket Equation for constant acceleration in the vacuum of space where the spacecraft is not significantly affected by the gravity of planets, stars or galaxies allows for the calculation of the amount of fuel needed for a given trip and the time needed to

accelerate to a given desired speed, such as 0.042c or 4.2% of the speed of light. The equation calculates the fuel needed as a proportion of the payload or crewed spacecraft:

$$\frac{Mi}{M_f} = e^{¿¿}) = 10^{0.4343¿¿}$$

The fuel needed as a proportion of the spacecraft equals 10 raised to the power of 0.4343 times (the velocity we want to achieve/the velocity of the exhaust of our rocket). The result times m, the mass of the payload, tells us how large Mi, the total mass of the rocket and fuel, must be to achieve our velocity goal.

The time in seconds required to achieve our desired velocity is calculated by dividing our desired velocity by our constant acceleration using common units of measure. For example, a speed goal in m/s divided by a constant acceleration rate in m/s^2 results in the number of seconds of burn required: 1,200 m/s divided by 9.8 m/s^2 = 123 seconds.

Here are some results of the Rocket Equation.

For the Apollo 11 spacecraft that took three men to the moon in 1969, the project required 64 times the spacecraft mass, in rockets and fuel, in order to get the spacecraft started toward the moon at 24,500 miles per hour. Fortunately, earth's gravitational pull slowed Apollo 11 sufficiently that it could slow itself further with a rocket burn and enter orbit around the moon rather than flying right past.

In November 2022 the somewhat larger, four to six passenger, Orion spacecraft was sent, uncrewed, to the moon at 24,500 miles per hour to start its trip; the effort required 73 times as much mass in rockets and fuel to get it to that point. It circled the moon at a greater distance than previous Apollo missions and then returned to earth where the empty crew cabin was retrieved after an ocean landing.

The SpaceX Falcon rocket delivers up to 243,000 pounds of payload to earth's orbit using 24 times the payload mass to get it in there. The Starship being developed by SpaceX would get 220,000 pounds of payload into earth's orbit using 48 times the payload mass to do so. The SpaceX moon-lander HLS, a version of the Starship module, will require about 48 + 20 refueling missions or 960 times the mass of the HLS before the HLS can rocket itself toward the moon. And the HLS, following a landing and takeoff from the moon's surface, won't have enough fuel to return to earth. Consequently, the HLS will be left behind while an Orion spacecraft will bring the astronauts home to earth.

As a final example, let's say you wanted to speed up Orion's trip to the moon by starting out at 50,000 miles per hour instead of 24,500 and assuming its Artemis rocket exhaust thrust value of 2.56 km/sec, we would need fuel amounting to 6,433 times our Orion payload. If we could increase our exhaust thrust value to 5 km/sec, we could cut this number to 90. But this doesn't even address the need to reverse your rockets to slow down to enter an orbit around your destination.

It is not easy to increase or decrease a spacecraft's speed in the unimpeded vacuum of space. In space the fuel needed is determined only by exhaust velocity and the speed you want to attain, that is, by the opposite forces of momentum. To increase or decrease your speed, you must throw away more of your ship, and that means you need more ship to throw away, that is, more fuel.

For example, if your ship is sitting in space and you want to accelerate at one g to reach 25,000 mph, you would need fuel amounting to 80 times the mass of your ship.

$$M_i \,/\, M_f = e^{(\frac{11.2}{2.56})} = 80$$

Here is a visual of what this looks like, spacecraft mass (S) to fuel mass (O):

S : O O O

Calculations using this equation are simplified by setting c = 1. Then if delta V is .3 and Ve is 1.24 x 10^-5 (3.72 km/s divided by c or 300,000 km/s) for example, you have [(1+ .3)/1 - .3)]^[1/(2 x 1.24 x 10 ^-5)] = 1.03/0.7 ^40.32 = 5,797,542. We can scratch this rocket right now as needing way too much fuel. We would need an enormously greater exhaust velocity Ve to reduce our fuel needs.

Summary of Rocket and Spaceship Terms and Calculations

When rocket engines are under development, they are tested to establish their thrust (in newtons, meaning kilograms x meters/second^2) and the mass burn rate (in kilograms per second) at which fuel is burned. Dividing the thrust by the mass burn rate gives the actual exhaust velocity. And we know that the gravitational force at sea level equals is 9.8 m/s^2 from general physics.

With these three empirical values, thrust, burn rate and the force of gravity, a very important efficiency metric can be defined. This is the specific impulse or Isp. It is regarded as analogous to miles per gallon in automobiles. You divide the thrust (kg x m/s^2) by the mass burn rate (kg/s) times the force of gravity and get a number which is in units of seconds. The Isp gives the Newtons of force per kilogram of mass flow of the propellants, a measure of an engine's efficiency in using fuel. But there is no correlation of the Isp to the amount of thrust. Low Isp chemical propellant rockets (around 3000 m/s exhaust velocity/9.8 m/s^2 = 306 Isp) have the highest thrust values, essential for getting anything off the earth.

A high Isp can deliver the same thrust using less fuel, thus reducing the fuel mass of a rocket. The fuel of the first stage of the Saturn V rocket made up 77% of the first stage mass and 60% of mass of the total rocket. This reflects the fact that getting out of the earth's gravity well requires enormous effort.

High Isp alternatives to chemical propellants are being researched and developed. But to achieve the greatest thrust you need both high exhaust velocity and a high mass burn rate.

One alternative is an ion plasma engine using electricity generated by solar panels or a small nuclear fission plant to dislodge electrons from some material and send the electrons out of the exhaust at very high speeds, such as 19,200 m/s to 78,400 m/s. But due to the tiny mass embodied in electrons this generates less than 100 Newtons of force.

Another area of research is a nuclear thermal engine that uses the heat generated by a nuclear fission plant to heat a fluid such as liquid hydrogen or even water to exhaust out the back of a spaceship. The nuclear fission/thermal rocket engine is a key developmental goal of NASA for a proposed crewed Mars mission in 2035. NASA estimates that exhaust velocities for liquid hydrogen propellent could reach 800-1000 Isp, 7800-9800 m/s exhaust velocity and 100,000 to 1,000,000 Newtons of force. This implies a fuel use rate of 100,000/7,800 = 12.82 kg/s to 1,000,000/9,800 = 102.04 kg/s.

Both options have high Isp but they also have lower thrust levels than chemical propellants due to the small fuel mass use rates. The low thrust values could never lift a significant load off the earth. But they could be useful for a vehicle already in space and well away from earth’s gravity. A ship’s acceleration, due to low thrust, would be slow but could reach speeds over time that are out of reach by chemical propellant rockets operating in space due to the fuel mass requirements. Chemical propellant rockets would require far too much fuel mass to be practical for general space travel. The Rocket Equation, discussed later, documents this fact quantitatively.

With the Isp value in hand, you can now calculate the effective exhaust velocity Ve (m/s) as Isp x 9.8 m/s^2, the gravitational force of earth at sea level.

<u>The Rocket Equation Outside a Gravitational Field</u>

Once you have the effective exhaust velocity, you are ready to calculate the mass ratio for the rocket using the famous Rocket Equation:

$$Mi \,/\, Mf = e^{(\frac{delta\ V}{Ve})}$$

where Mi is the initial mass of the rocket and fuel and payload

Mf is the final mass or the mass of the payload

e is the transcendental number 2.718…

delta V is the change in velocity that we want to achieve

Ve is the exhaust velocity of the rocket.

And Mi – Mf = Mp, the propellant mass.

The standard Rocket Equation applies to any rocket in outer space away from any gravitational field.

Given the delta-V or change in velocity you want to achieve, and the exhaust velocity (Ve) of your rocket engine, the equation tells you the relationship of the permanent spacecraft and the fuel requirement to reach delta-V.

Another way to express the Rocket Equation is

Mi = Mf e^(delta V/Ve).

This tells us that the initial mass of the rocket ship is a multiple of a factor defined by e^(delta V/Ve), times the final or post-burn mass of the ship.

This applies to a one-time acceleration of the rocket. If you want to decelerate the ship and stop at some destination in space, the initial mass is not two times the one-way result but rather

Mi = Mf [e^delta V/Ve]^2.

For example, if Mi = Mf e^(11.2/3.05) = 39 Mf, then an acceleration at the start and a deceleration at the destination would be 39^2 Mf or 1,521 Mf, already an impossible number. This reflects the tyranny of the Rocket Equation. Travel to a

destination and back to the origin of the trip, without refueling, would require Mi = 39^4 Mf or 2,313,441 Mf! This is more than 2 million times the permanent spacecraft.

The general equation for multiple starts and stops is

Mi = [e^(delta V/Ve)]^n, where n = the number of starts and stops.

The equation can be adjusted to find delta-V given the other terms of the equation:

Delta V = Ve ln (Mi/Mf).

An example would be delta V = 3.05 km/s x ln (3/1.3) = 3.03 x 0.836 = 2.55 km/s or 2,055 m/s.

The 3 divided by 1.3 n the equation are the approximate Saturn V first stage masses before and after the booster burn of 165 seconds. The masses are actually millions of kilograms but here only the relative values matter so we can drop the millions.

This is the Rocket Equation outside a gravitational field.

<u>The Rocket Equation Within a Gravitational Field</u>

For a rocket ship seeking to leave earth for orbit around the planet or to set off for our moon or another planet within our solar system, the Rocket Equation is even more tyrannical.

The corresponding alternative equations are:

Mi/Mf = e^(delta V + gt)/Ve

Mi = Mf [e^(delta V + gt)/Ve)]

Delta V = Ve ln (Mi/Mf) - gt

where g = the gravitational field strength (earth = 9.8 m/s^2, our moon = 1.6 m/s^2) and t = the number of seconds of rocket burn time.

Using the same example as before and adding in earth gravity of 9.8 m/s^2 and using 165 seconds of rocket burn time of the first stage of Saturn V,

Mi/Mf = e^(11,200 + 9.8 x 165)/3,050 = 67 (rather than 39 in the previous example).

The fuel mass required is 67/39 or 1.7 times greater than the same scenario in outer space.

I have expressed delta-V and Ve both in meters/second because I am using gravity in meters/second and we must keep our units consistent with each other.

And for Saturn V the delta V = Ve ln (Mi/Mf) – gt = 3,050 ln (3/1.3) – 9.8 x 165 = 3,050 x 0.836 – 1,617 = 933 m/s.

Gravity restrains the delta-V that can be achieved compared to what is possible in outer space where gravity isn't a significant factor.

Staged Rockets

It has not been possible to make a one-stage rocket that can reach earth orbit or leave directly from earth to outer space and beyond.

The Saturn V / Apollo missions to the moon in the 1960s and 1970s managed their task by using a three-stage rocket with disposable stages. The total mass of the Saturn V was 102 times larger than the ship sent to the moon, which began its trip at about 25,000 mph after being propelled from earth orbit by the third-stage of the rocket.

The Rocket Equation may be applied to each stage of a multi-state rocket and then summed to get a overall result.

Acceleration and Velocity Outside a Gravity Field

The acceleration of a rocket is a function of rocket burn time.

In outer space where gravity is insignificant,

a(t) = N/Mi-Rt

where a(t) equals acceleration at time t (s)

N is the Newtons of force applied by the rocket burn (kg m/s^2)

Mi is the initial mass of the rocket (kg)

R is the mass burn rate of the rocket (kg/s)

Given the mass of the rocket in kilograms and the thrust in newtons, we can divide the thrust by the mass to get the acceleration of the rocket at liftoff at t = 0 in meters per second squared. If the mass of the rocket remained the same the acceleration would remain the same, but as the rocket burns and exhausts fuel the mass of the rocket declines rapidly. This leads to a continuing increase in the rate of acceleration as the rocket rises into the sky.

Richard Feynman, in Feynman's Tips On Physics (2006) on page 81 presents a formula that takes the fuel use and increasing acceleration into account to give the velocity of the rocket,

v(t) = -Ve ln (1-R x t/Mi)

where v is the ship velocity (m/s), Ve is the exhaust velocity (m/s), R is the mass burn rate (kg/s), t is the number of seconds of burn, and Mi is the original mass of the ship (kg).

How long would it take a spaceship to reach a specific velocity goal? Feynman provides a formula for this too for the increasing acceleration case,

t = (Mi/R)(1-e^-Vgoal/Ve)

where t is time (s), Mi is the original mass of the ship (Kg), R is the mass burn rate (kg/s), e is 2.718, Vgoal is the velocity goal, and Ve is the exhaust velocity. The value of the second term in the equation involving the number e gives the proportion (in decimal form) of the entire rocket that must be fuel to achieve the velocity goal. For example, (3 million/12,885) (1-e^-(11.2/3.05) = 233 (0.975) = 227 seconds.

If the throttle is used to maintain constant acceleration as fuel mass is burned, then we can simply divide the velocity goal by the acceleration rate, and t = Vgoal(m/s)/acceleration (m/s^2) = seconds of burn time.

Acceleration and Velocity Within a Gravity Field

$a(t) = (N-Rgt)/(Mi-Rt)$

Where the new term Rgt subtracts from the Newtons of force. Rgt is the mass burn rate times gravity times burn time. By lowering the Newtons of force propelling the rocket, gravity reduces acceleration.

The Feynman equation for velocity adjusted for gravity is

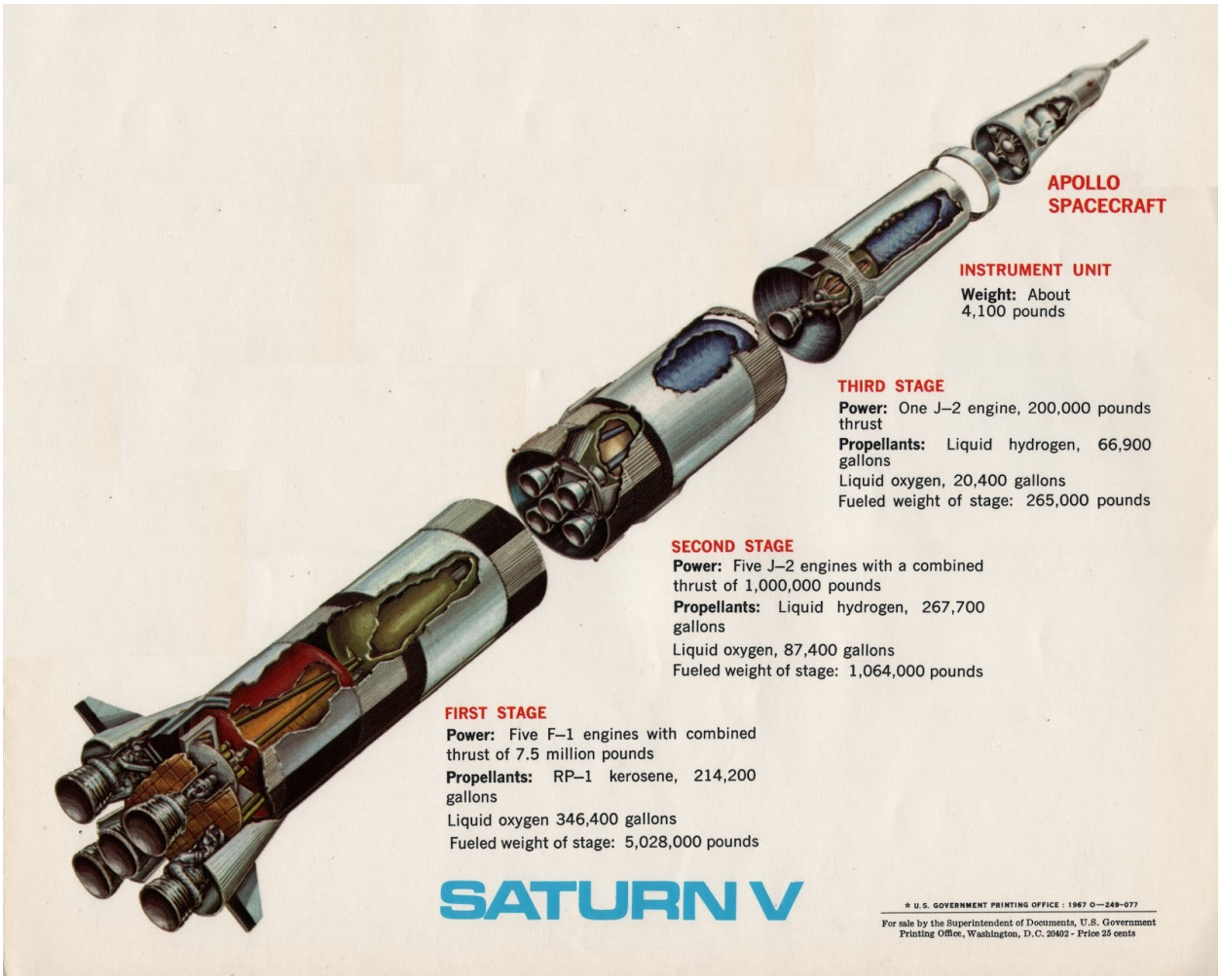
$V(t) = (-Ve + gt) \ln [1-(Rt/Mi)]$

In a gravity field the time to reach a velocity goal will take longer since gravity constrains velocity every second. Earth gravity constrains upward motion of a rocket by 9.8 meters every second.

B: Real Rockets, Saturn V (1967) to Starship (2025)

A Real World Example of Space Travel: NASA Saturn V, Apollo 11 Trip to the Moon (1969)

I will use the Saturn V rocket that powered Apollo 11 off the earth in 1969 as an example of how a rocket works.

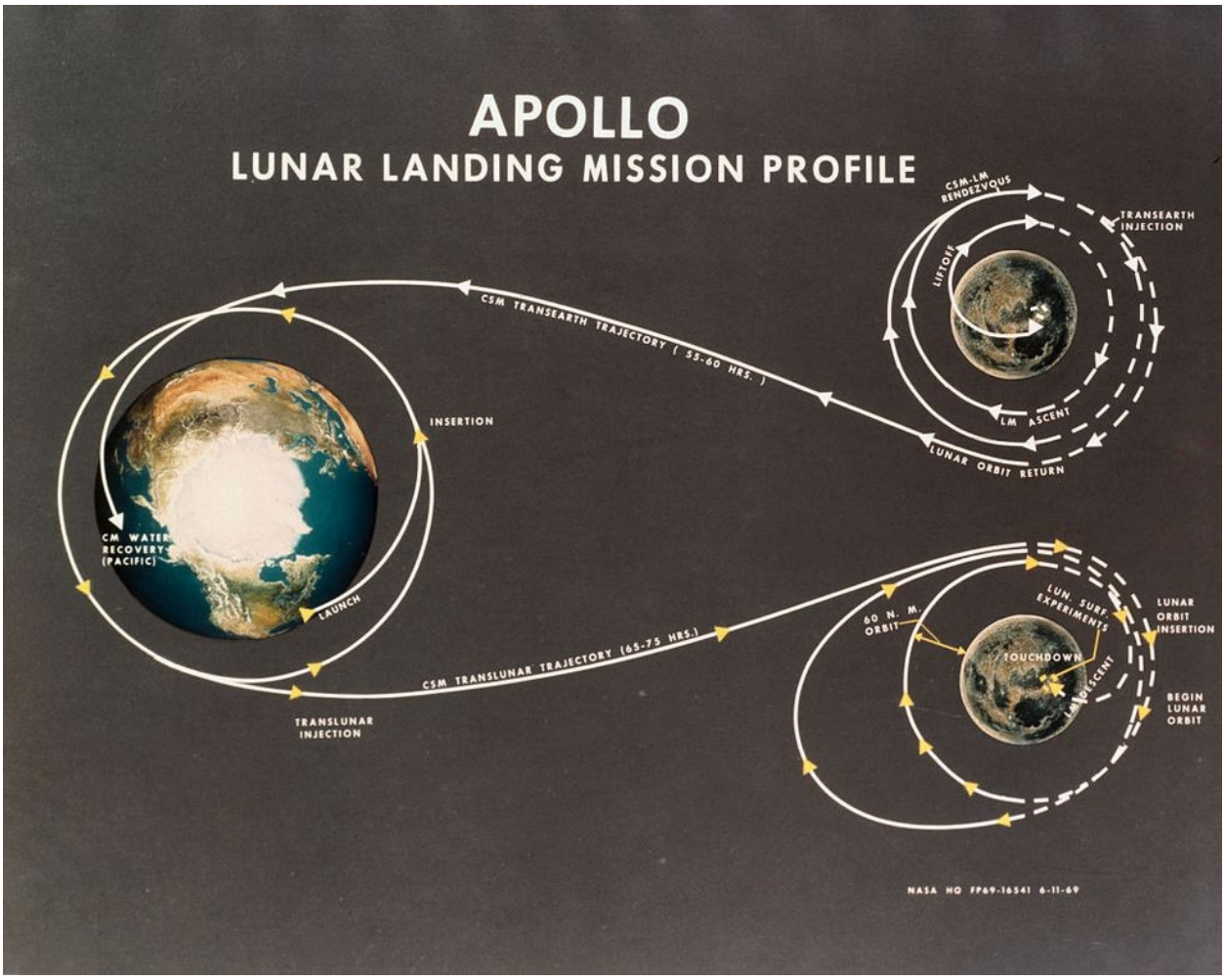

APOLLO SPACECRAFT
INSTRUMENT UNIT
Weight: About 4,100 pounds
THIRD STAGE
Power: One J–2 engine, 200,000 pounds thrust
Propellants: Liquid hydrogen, 66,900 gallons
Liquid oxygen, 20,400 gallons
Fueled weight of stage: 265,000 pounds
SECOND STAGE
Power: Five J–2 engines with a combined thrust of 1,000,000 pounds
Propellants: Liquid hydrogen, 267,700 gallons
Liquid oxygen, 87,400 gallons
Fueled weight of stage: 1,064,000 pounds
FIRST STAGE
Power: Five F–1 engines with combined thrust of 7.5 million pounds
Propellants: RP–1 kerosene, 214,200 gallons
Liquid oxygen 346,400 gallons
Fueled weight of stage: 5,028,000 pounds
SATURN V
* U.S. GOVERNMENT PRINTING OFFICE : 1967 O—249-077
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 25 cents

The fully fueled rocket with the three Apollo 11 astronauts aboard weighed 2,923,387 kg. Multiplying by 9.8 m/s^2 we get 28,649,193 Newtons of gravitational force that must be overcome. Much more force was required to send the rocket into the sky.

The Saturn V was a three-stage rocket with each of the three stages and their frame mass released after it had done its job. Staging like this is really the only practical way to launch large payloads such as the Apollo 11 spacecraft from the earth into orbit and beyond. This is a consequence of the Rocket Equation. The fuel requirements for a single stage chemical rocket are too great for practical use.

The first step for the Apollo 11 mission was to achieve a parking orbit around the earth before setting out for the moon. It took

three booster stages of the rocket to get the Apollo moon craft, or CMS, into earth orbit.



The first stage always does the heavy lifting because the pull of gravity is strongest at the surface of the earth and the fully fueled ship is at its heaviest. In the case of Saturn V the first stage booster had five enormous rocket engines that produced a combined 33,400,000 Newtons of continuous force. Since we know the exhaust velocity was 2,640 m/s, we can divide this into 33,400,000 Newtons to get the mass flow rate of 12,652 kg/s. Dividing this number by five engines gives 2,530.4 kg/s per engine. The thrust per engine was 33,400,000/5 = 6,680,000 Newtons.

Subtracting the Saturn V mass Newtons from the first stage rocket Newtons gives a net force of 4,750,807 Newtons beyond

the force needed to counter earth's gravity. This net force is what sent Apollo 11 racing from earth into the sky. The first 28,678,426 Newtons is needed just to counter earth's gravitational pull. If one didn't have to counter the gravitational pull of earth, far less force would be needed to lift the rocket. Typical values of the thrust to weight ratio for rockets, with both thrust and weight expressed in Newtons, run from the Apollo 11 Saturn V first stage booster ratio of 1.17 to the Apollo 11 lunar ascent module ratio of 2.

Now if we divide this net force by the weight in kg of Saturn V we will get the acceleration at lift off. It was 4,721,574/2,923,387 or 1.6 m/s^2. This is about 0.16g (=1.6/9.8). As fuel was furiously burned by the five first-stage engines at a rate of nearly 13,000 kg of fuel and oxidizer per second, the mass of the rocket declined rapidly. The booster net thrust force grew as well, and the acceleration increased. As a result, the g-force aboard Saturn V rose. At around 130 seconds into flight, the central engine of the first stage rocket was shut down when the acceleration plus the pull of gravity reached about 3.6 g's to keep the g-force below 4 g's for the safety of the astronauts. The thrust dropped to 26,720,000 Newtons and the mass burn rate dropped to 10,122 kg/s.

The other four first-stage booster engines shut down at 168 seconds or 5.6 minutes after launch. Almost 60% of the Saturn V's mass was exhausted by the five first-stage booster engines during those first 168 seconds. That amounted to nearly 0.6 x 28,678,426 or 17,207,056 Newtons or about 1,750,000 Kg of spent fuel. Saturn V had only partially overcome earth's gravitational pull and was about 38 miles above earth and 58 miles downrange from its launch site. The Saturn V had turned from a vertical path to a near horizontal path soon after launch in order to maximize its speed. The exhausted first-stage booster frame was now released to fall back to earth, reducing the remaining weight of the rocket by 137,000 Kg, the weight of the empty first stage frame.

The second-stage booster fired and took Saturn V to 115 miles above earth, shut down and was itself released to fall back to earth. This decreased the weight by a total of 480,000 kg of fuel and 11,158 kg of frame. The CMS was still only in a very low earth orbit. But the rocket had now reached a speed, height and weight that allowed the next stage to push it into a higher orbit.

The launch escape module at the tip of the rocket was released, reducing the weight by 3,632 kg.

The third-stage booster now fired and took Saturn V into a higher orbit around earth traveling at 17,500 miles per hour. Stage three now shut down while Saturn V circled the earth. When the position to strike out for the moon was right, midway through the second orbit, stage three fired again and sent Saturn V on its journey to the moon at an initial speed of 24,500 miles per hour. Stage three then shut down and was released from the spacecraft to drift in space. This decreased the ship's weight by a total of 137,260 kg.

The Command/Service module and the Lander/Ascent module each had their own engines and fuel to accomplish each of the tasks ahead. The Command/Service engine, known as the STS, had 750 seconds of burn capability and a thrust value of 91,190 Newtons of force. This gave it a total impulse, thrust times seconds of burn, of 68,392,500 Newtons. The STS engine was designed to restart up to 50 times and could fire for a period of anywhere between 0.4 seconds and 12.5 minutes. There was about 22,190 kg of propellant in the CMS (750 seconds of burn time x 29.59 kg/s). The total CMS at this point had a mass of 28,801 kg. The STS engine was fired for 3 seconds in a course correction burn on the way to the moon. Approaching the moon, the STS was fired in a retrograde fashion for 357.5 seconds to slow the CMS to a speed where it could insert itself into a moon orbit.

The lunar landing module engine had 44,316 Newtons of thrust versus the 24,467 Newtons of the moon's gravity, 15,103 Kg x 1.62 m/s^2 moon gravity, to offset when landing. It planned to

land with two minutes of burn time remaining but ended up with only about 20 seconds of burn time left on landing.

The engine of the lunar ascent module had a thrust of 15,700 Newtons versus the 7,776 Newtons of the moon's pull on the mass of the ascent module, 4,800 kg x 1.62 m/s^2.

After the lunar landing, blast off in the ascent module, docking with the Command/Service module orbiting the moon, and transferring the two astronauts and 22 kg of moon rocks to the CMS, the lunar Lander was released and probably fell to the moon's surface in a few months.

While behind the moon and out of communication with earth, the STS engine was fired by the astronauts for 148 seconds, burning about 4,580 Kg of fuel, to escape the grip of moon's gravity and power its way back to earth at about 5,900 mph. The CMS had been orbiting the moon at about 3,650 mph and needed a speed of 5,300 mph or more to escape from the moon's gravitational hold.

After the rocket burn, the craft continually slowed as the moon's gravity continued to pull at it. At 8,100 miles from the moon the craft had slowed to 3,318 mph. This slowing continued until the craft reached the L1 Lagrange Point between earth and the moon at about 37,260 miles distance from the moon where earth and moon gravitational forces are exactly equal. This is about 15% of the distance from moon to earth. After crossing the L1 Lagrange Point the CMS began receiving the benefit of earth's gravity as it coasted back toward earth at increasing speed. The CMS made one course correction burn of about 15 seconds using 469 kg of fuel. The entire trip from moon back to earth traveling 238,900 miles took 72 hours giving an average speed of 3,318 mph.

Upon reaching earth, the Service module with its STS engine was released. The STS seems to have used about 513 seconds of its capacity of 750 seconds of burn time and had been started four times out its potential of 50 times.

The Command module entered earth’s atmosphere at nearly 25,000 miles per hour under the pull of earth’s gravity and was slowed by its angled entry into earth’s 60-mile-deep atmosphere. Heat shields protected the three astronauts from the extreme heat generated during the rapid entry through the atmosphere. When the Command module was slowed enough, to about 300 miles per hour, parachutes deployed and the Command module and its three astronauts splashed down safely in the Pacific Ocean.

Here is a summary in terms of kilograms of the original mass of the Apollo 11 mission until the splash down in the Pacific Ocean of the Command Module carrying the three astronauts. This example illustrates how space travel works.

Kiligrams of mass	Changes	Mass
Mass at launch on earth		2,923,387
First stage booster burnout and release	(2,262,536)	660,851
Second stage booster burnout and release	(491,158)	169,693
Launch escape module release	(3,632)	165,061
Third stage booster burnout and release	(137,260)	28,801
CMS module coasts to the moon		28,801
Moon lander and ascent vehicle left behind	(15,103)	13,483
Fuel burns and release of Service Module	(8,551)	4,932

Command Module with three astronauts splash into Pacific Ocean
4,932

Imagine driving to the grocery store and having to leave 98.8% of your car along the roadside before getting home! But this is what space travel is all about.

The mission took 102 times the CMS in terms of the kilograms of the ship that was sent to the moon. If the returning Command Module is considered the payload of the mission, it took 593 times the payload in engines, frame and fuel to complete the Apollo 11 mission to the moon.

Another informative way of looking at the Saturn V/Apollo 11 mission is in terms of the total Newtons of force or impulse of the major aspects of the trip. Impulse consists of the Newtons of force per second times the number of seconds of rocket burn time. Here are the numbers.

Getting the CMS into earth orbit and on its way to the moon
7,529,910,000

CMS course correction and orbit around the moon
41,366,191

Lunar lander descent and landing on the moon
32,855,757

Lunar ascent module to lunar orbit
7,850,000

CMS exit from lunar orbit and course correction to earth
14,863,970

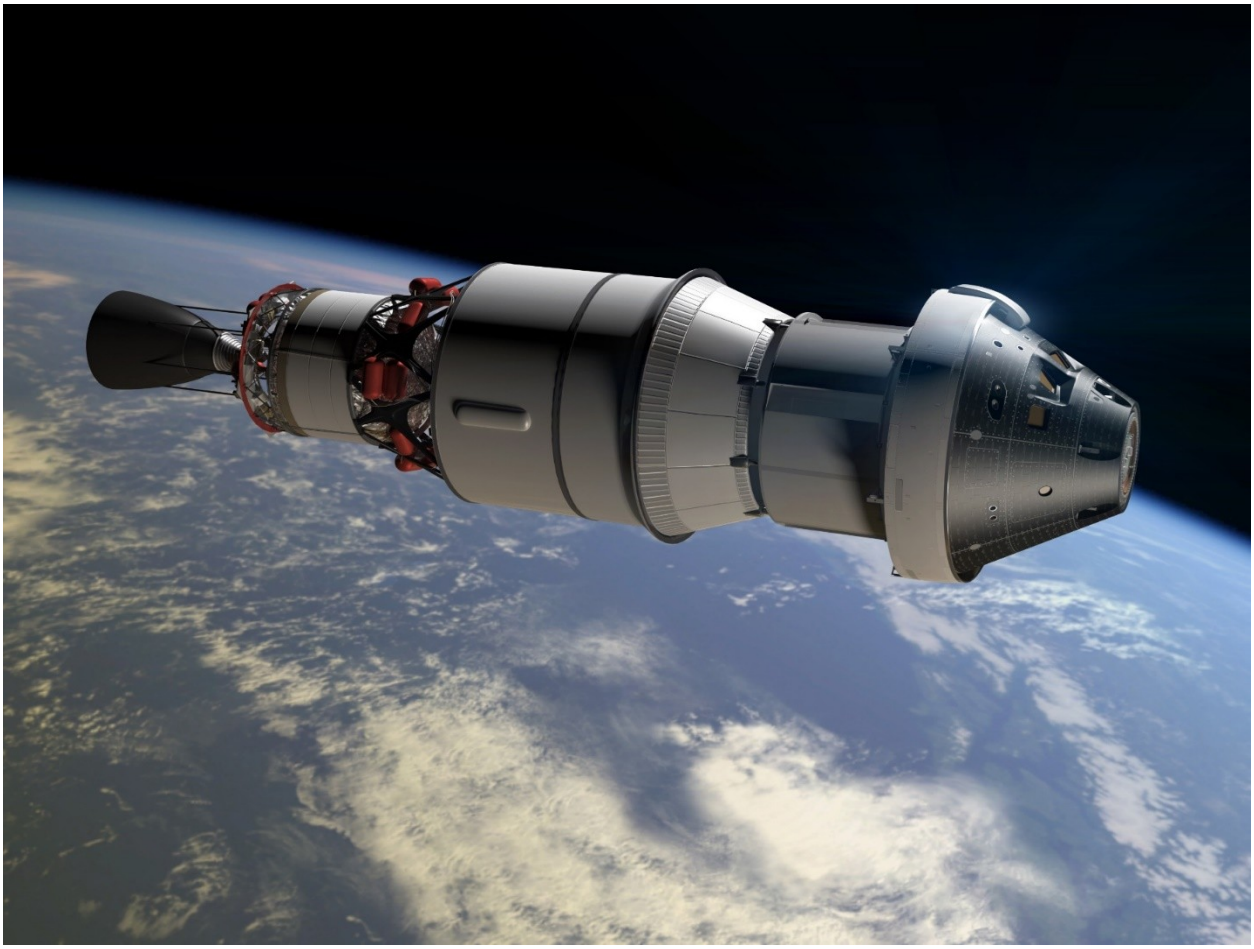
Grand total of impulse for the mission
7,618,995,918

We can calculate that it took 98.83% of the total impulse (7,529,910/7,618,918) to get the CMS into orbit around earth and then start it on its way to the moon at about 25,000 miles per hour. This works out to 261,446 Newtons per kilogram of mass sent to the moon.

NASA Artemis/Orion Trip Around the Moon (2022)

In November/December 2022 NASA successfully sent an uncrewed spacecraft around the moon and recovered the crew capsule on earth in preparation for a planned four-person crew aboard the same craft in late 2024 to repeat the fly-around of the moon, which didn't happen. The Orion Command and Service module was launched by a new and very powerful rocket called SLS (Space Launch System). It now appears that the SLS is overbudget and behind schedule and may be cancelled. And it has recently been revealed that the Orion earth reentry module suffered more than expected damage to its heat shield when it reentered earth's atmosphere in December 2022 and the reentry module may not be safe for crew members. The empty crew capsule entered the earth's atmosphere at nearly 25,000 miles per hour and external temperatures reached about 5,000 degrees Fahrenheit.

This is known as the Artemis program and it is a huge follow-on to the Apollo program of the 1960s and 1970s. The NASA moon module is called the Orion and will carry four astronauts. The crewed command module falls to earth upon its return from the moon just as the Apollo crew capsule did, slowed by parachutes and picked up in the ocean.



For future moon landings and for building and supplying a future moon base, NASA has contracts with SpaceX and with Blue Origin to build moon landers. The Orion is designed to fly around the moon and to orbit the moon and to return astronauts to earth but it is not designed to land on or take off from the moon. This is where SpaceX and Blue Origin come in, private companies owned by Elon Musk and Jeff Bezos, respectively.

SpaceX and the Starship: HLS Version

NASA gave SpaceX a $2.9 billion contract in 2021 to develop a variant of the Starship space vehicle called HLS to travel to the moon, accept the transfer of astronauts from Orion while circling the moon, land on the moon, take off again, and transfer the astronauts back to Orion. Then HLS will be released to fall to the moon's surface while Orion carries the humans back to earth.

SpaceX already has a proven and reusable booster launch vehicle used with its two-stage Falcon 9 orbit service rocket. The Falcon 9 first-stage booster rocket has landed numerous times under its own power on ocean landing ships and on dry land. Reusability of the Falcon 9 booster rocket is the hallmark of SpaceX and saves a great deal of time and money when launches are frequent enough. It may place other orbit lift providers in competitive jeopardy, such as the new expendable European Ariane 6 rocket which successfully launched and deployed satellites in orbit on July 9, 2024.

As well as its rocket and space programs, SpaceX has a worldwide communications network of orbiting satellites called Starlink.

Starship is SpaceX’s own creation, the brainchild of the company’s owner, Elon Musk. He sees the Starship program as a

means to deliver thousands of additional Starlink satellites into orbit quickly and efficiently, as a vehicle for space tourism for which Starship is already taking bookings for trips around the moon, to support the NASA moon missions, and as a vehicle for Musk's dream of transporting one million humans to Mars by 2050 to live in a city established there. The Starship passenger module is designed to carry about 100 passengers. If the transport to Mars got underway in 2040, it would require 10,000 trips or nearly three trips per day to transport one million people.

Starship has been launched numerous times. Each test launch has been an incremental learning experience aimed at improving the next. One booster has returned and landed at its takeoff point in Texas. No second stage has yet attempted to land on earth. Whether heat shield technology can protect the integrity of the ship and any equipment or humans aboard remains an open question.

The Starship consists of just two modules, the main booster rocket called Super Heavy and the booster/payload/personnel module called Starship or just Ship. Both modules are intended to be reusable, with potential cost and time savings. The HLS module would remain in space and be refueled there and be used for the NASA moon missions. The HLS would fly to the moon and go into orbit. The Orion spacecraft, launched using the SLS rocket, would carry the astronauts to the moon and into orbit there. The astronauts would transfer from the Orion to the HLS and the HLS would then land on the moon and stay for a week. At that point the HLS would take off and again go into moon orbit. The astronauts would transfer back to the Orion spacecraft, which would then carry them back to earth where they would enter earth's atmosphere inside a landing capsule and splash down in the ocean. The HLS, meanwhile, with inadequate fuel remaining to exit moon orbit or return to earth, would circle the moon until falling to crash on the surface under the moon's gravity. This whole scenario is recognized as being costly, dangerous and possibly hopelessly foolhardy.

Starship booster rocket has 33 Raptor engines designed by SpaceX burning methane and oxygen as fuel and optimized for sea-level operation. The Starship module has six Raptor rocket engines using methane and oxygen as fuel with three engines optimized for sea level operation and three optimized for vacuum operation.

The version 1 Raptor engine generates 2,080,000 Newtons of force at sea level. The 33 Raptors of the Super Heavy booster have a combined force of 68,640,000 Newtons at liftoff, making it the most powerful rocket ever built and fired. The vacuum Raptors of the Starship module each generate 2,405,000 Newtons.

The overall Starship when fueled and full of cargo weighs about 5,000,000 kg. The force of gravity pulling on this weight is 49,000,000 Newtons. The net difference between the booster Newtons and the complete Starship is 19,640,000 Newtons of force. Dividing the net force by the 5,000,000 kg weight of Starship gives an acceleration at liftoff of 3.5 m/s^2, just over 1/3 g. Thirty-three Raptor engines burn for 168 seconds and have a thrust-to-weight ratio of 1.40. The booster then separates and may return to land on earth, available for reuse. The Starship module's six Raptor engines then push it into earth orbit. The six Raptor engines of the Starship module have 13,455,000 Newtons of force to push the ship higher and into earth orbit. The mass burn rate for both versions of the engine is 650 kg/s (510 kg of O2 and 140 kg of CH4). The respective Isp values are 327 s (sea level) and 380 s (vacuum).

SpaceX is constantly working to increase the Raptor engine thrust. Musk says that the version 2 Raptor (2025) generates 2,288,000 Newtons of thrust. A version 3 (2025/26) is supposed to generate 2,615,000 Newtons of thrust. A version 4 goal is 4,413,000 Newtons.

It is reported that the engines can be throttled back to 40% of capacity, which would give plenty of leeway to keep g-forces safe and comfortable for any human passengers.

As for the NASA-contracted HLS module, the theory is that once placed in earth orbit, many refueling flights of Starship will then be launched to refuel the HLS craft and enable it to travel to the moon, land on the moon, return to orbit and transfer its two astronauts to the Orion craft waiting in orbit. Then the HLS will be left behind and Orion will return the astronauts to earth. The number of Starship launches needed to carry fuel into orbit to transfer the fuel to the HLS before a moon trip can be launched has been estimated to be in the high teens. The fuel capacity of the Starship module is 1,201,284 kg. If it takes 18 Starships to refuel the HLS in orbit, this says that each flight will carry 68,738 kg of fuel for transfer to HLS. The payload module specifications indicate it can carry up to 100,000 kg of payload.

Blue Origin: New Glenn and Blue Moon

Blue Origin leads a consortium of companies on a NASA moon lander project including Blue Origin, Lockheed-Martin, Draper, Boeing, Astrobotics and Honeybee Robotics. Blue Origin was selected as a second contractor for a moon lander based on the schedule, cost and technical strength of their proposal.

The New Glenn launch vehicle, named after astronaut John Glenn, is a two-stage rocket. The first stage is powered by seven newly developed BE-4 engines, each delivering 2,500,000 Newtons of thrust for a total thrust of 17,500,000 Newtons. After initial launch and separation, it will return to earth and land on a landing ship at sea under its own power for later reuse. The second stage uses two BE-3U engines with 710,000 Newtons of thrust each. This will power the lunar lander, Mark 2 or MK2, into earth orbit. The New Glenn had its initial launch in January 2025. On November 13, 2025, it had a second successful launch and landing of its booster back on earth on a drone ship in the Atlantic Ocean.

Eventually, the plan is to send a tug with its own three BE-7 engines and a refuel tanker into earth orbit separately, after which they will join up to form a permanent gateway platform orbiting earth. When the MK2 enters earth orbit, it will

rendezvous with the gateway and refuel for the trip to the moon under its own power. Later, an Orion return capsule will be sent up to itself rendezvous with and attach itself to the gateway, awaiting the return of the MK2. The Blue Moon will land on the moon, ascend back to a moon orbit and power its way free of the moon's gravity to return to earth.

On its return, the Blue Moon will dock at the gateway and the astronauts will transfer to the Orion return capsule. They will then release from the gateway, briefly fire thrusters to slow down and begin their fall to earth under the force of gravity.

The Blue Moon is to have a 20,000 kg payload capacity compared to the Starship 100,000 kg payload capacity. On the other hand, the refueling needs of Blue Moon are far lower than the needs of the Starship, 29,000 kg versus 2,300,000 kg for Starship.

The Blue Moon is designed to carry four astronauts and to remain on the moon for up to 30 days. The Blue Moon will use three BE-7 engines, each with 44,500 Newtons of thrust using liquid hydrogen (LH2) as propellant and liquid oxygen (LOX) as oxidizer. The engines have multiple restart capability and a 20% to 100% throttle range. The fully loaded Blue Moon weighs 45,000 kg, drawing 72,900 Newtons with moon's gravity. The three BE-7 engines generate 133,500 Newtons of force to counter moon's gravity. They are to bring the Blue Moon to a safe landing on the moon and later an ascent back to lunar orbit and then will power the craft back to earth to the gateway orbiting there.

The Blue Moon project will also include a disposable uncrewed cargo lander able to deliver 30,000 kg of payload to the moon or a reusable version capable of delivering 20,000 kg of payload.

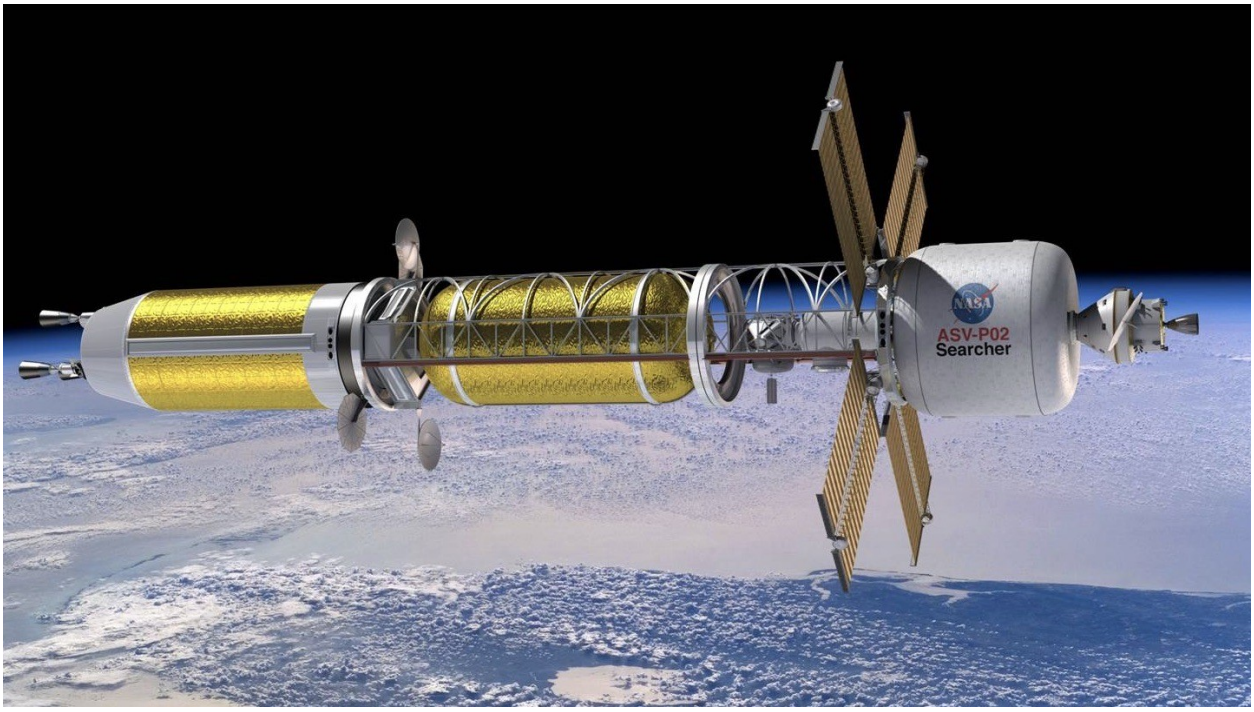
<u>The European Space Agency Argonaut Moon Cargo Lander</u>

The European Space Agency is developing a new Ariane 6 rocket, which had its initial launch on July 6, 2024. It is also developing a cargo moon lander called Argonaut. The Argonaut will be uncrewed and be capable of delivering 2,100 kg (4,620 pounds) of supplies, instruments or materials for moon-based operations.

Argonaut will be launched directly from earth to the moon by a two-stage Ariane 64 rocket. The lander would remain on the moon and not be reusable.

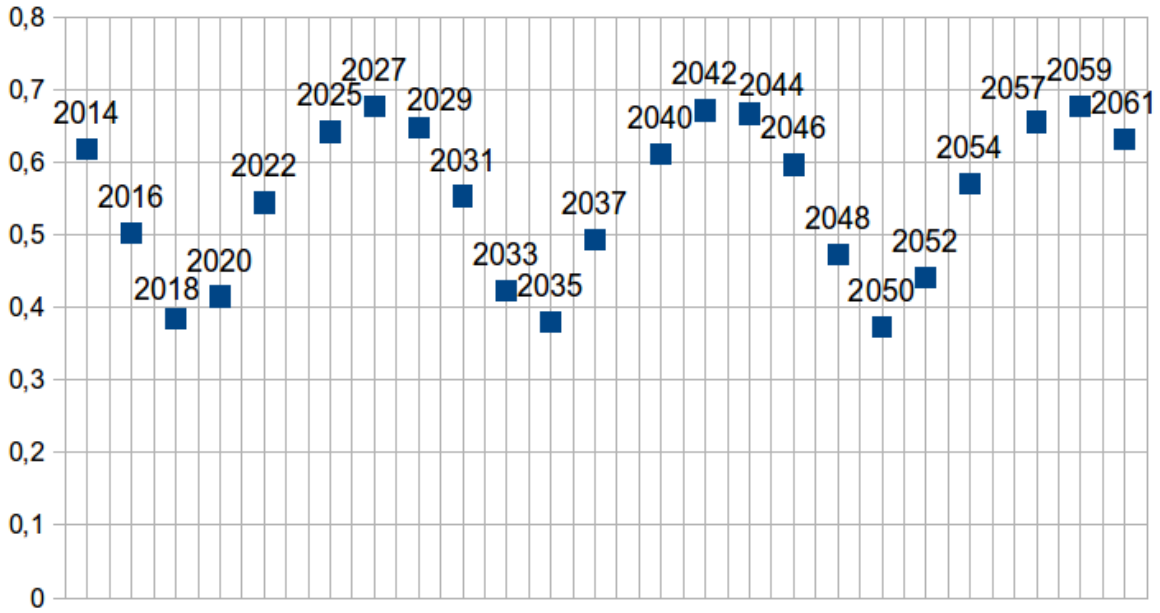
Planning for a Human Mars Mission

Numerous other governments and private companies are working on rockets as well as lunar and Mars craft. NASA has many other contractors than SpaceX and Blue Origin working on diverse rocket engines of various kinds, spacecraft designs, lunar and Mars landers, spacesuits and all aspects of space travel requirements. In particular, NASA has issued contracts for the development of a nuclear-thermal rocket for use in deep space, such as a crewed trip to Mars.

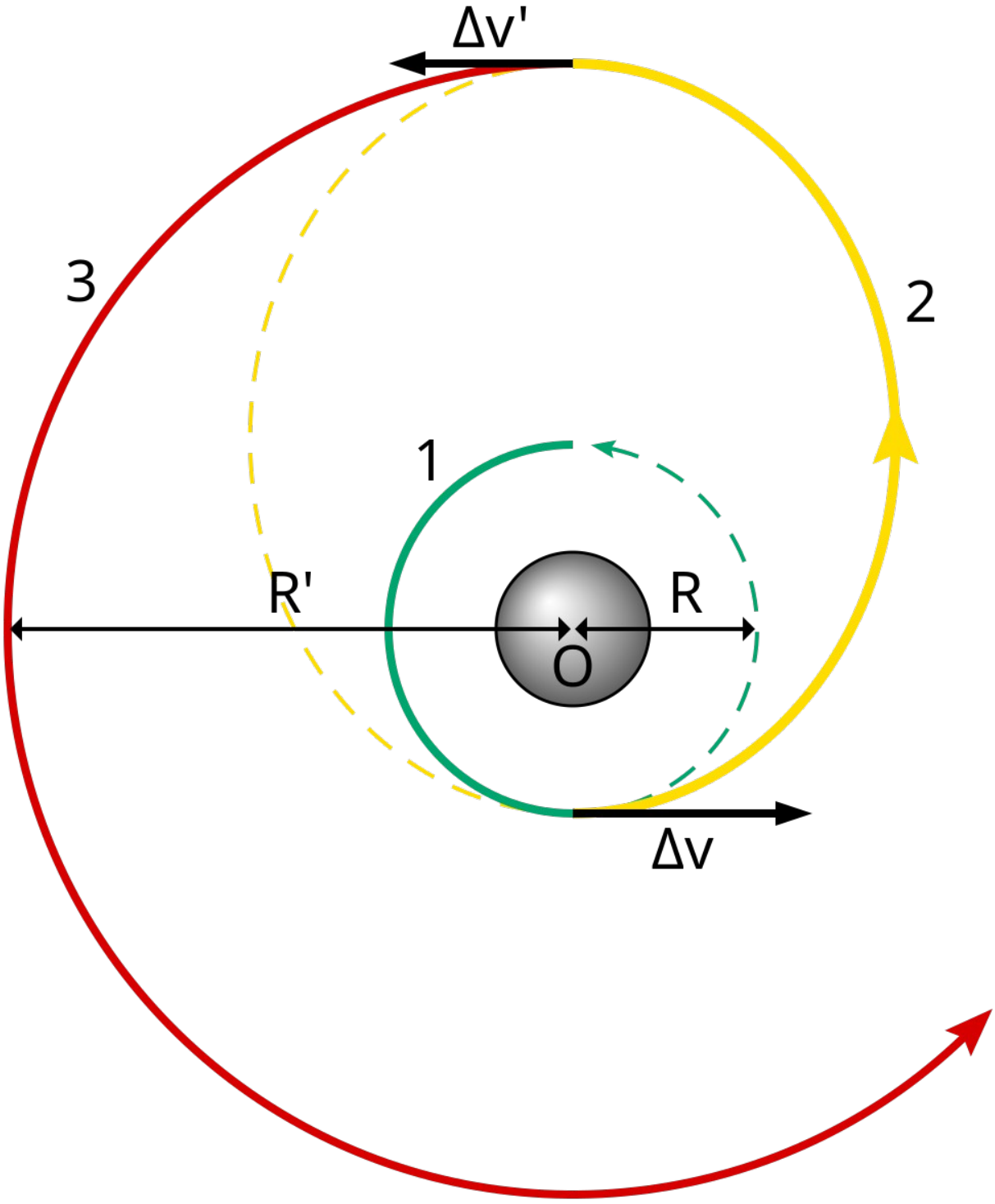


The nuclear-thermal rocket engine under development aims to achieve an Isp of 900 compared to the chemical rocket engine Isp of 300 or a bit more. This would allow for the same thrust from the nuclear-thermal engine as the chemical engine but with 1/3 the fuel use rate, reducing the mass of fuel that needs to be carried.

The elliptic orbits of Earth and Mars around the Sun bring the two planets into a closer distance relationship in a periodic fashion about every 26 months. Looking ahead, the next near-distance window is 2025 and additional windows open every two years after that. The near-distance values range between 35,000,000 and 72,500,000 miles. The furthest separation between the two planets is 249,000,000 miles. Naturally, any flights to Mars would seek to take advantage of the near approaches of the planets every two years and several optional trajectories have been worked out.



The higher numbers at left indicate a closer approach of mars and earth.



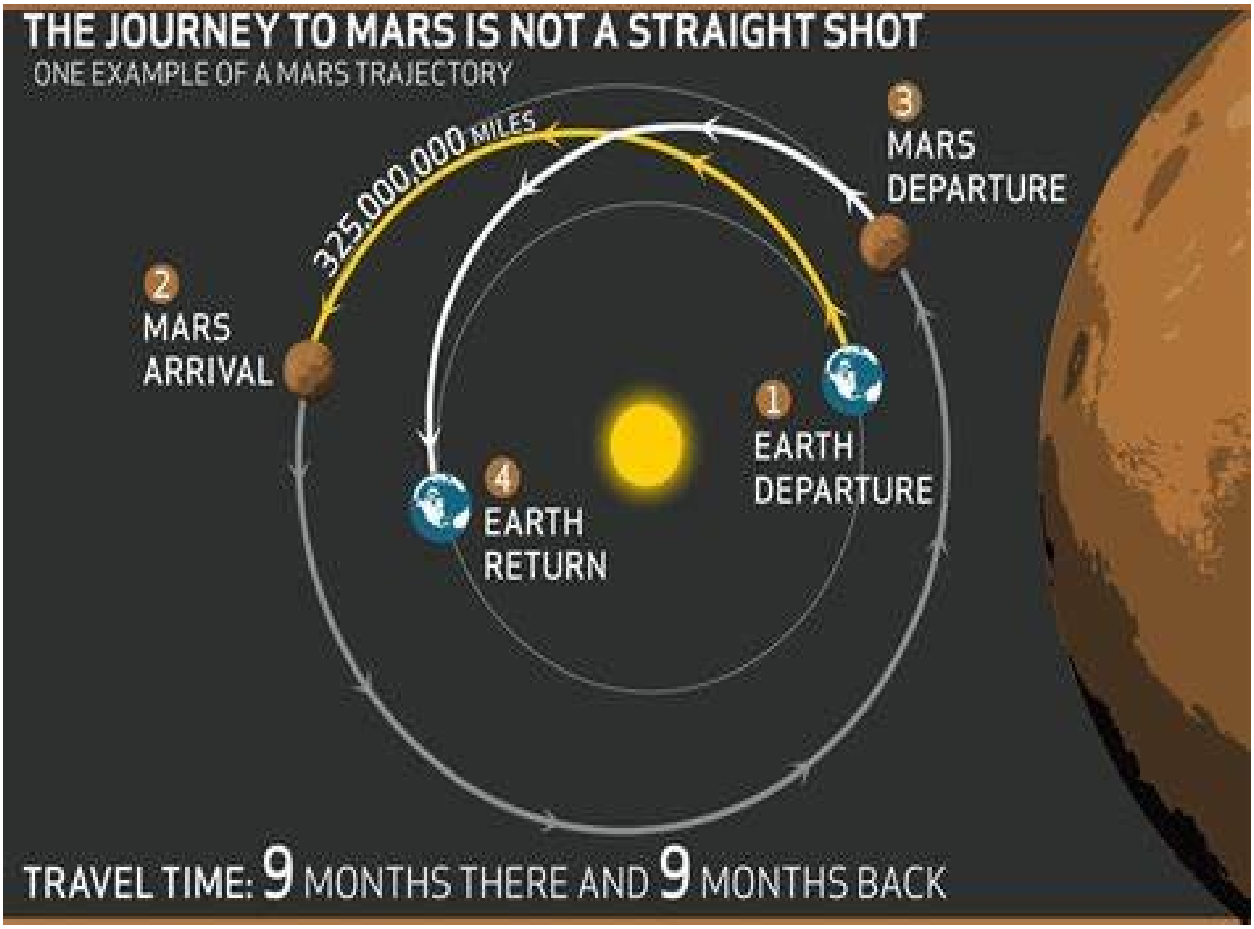
The Hohmann Transfer Orbit, worked out in 1925, involves circling the earth twice at two increasingly larger orbits, using two rocket engine burns to change from one orbit to another, thus sending the ship on a course to meet up with the Mars orbit. The

Hohmann Transfer Orbit involves traveling 141,202,000 miles each way and would take nine months to reach Mars, a 26 month wait for another orbit window and a 9 month trip back to earth. The Hohmann Transfer Orbit trajectory requires the least amount of fuel for a Mars trip but must travel more than four times the closest distance between Earth and Mars. All Mars missions to date have used the Hohmann trajectory to minimize fuel requirements.

NASA and others are contemplating two other routes to and from Mars.

One is called the opposition-class mission. This is a 640-day total mission involving a gravity assist from Venus on a 430-day trip to Mars and a 180-day return trip back to earth. Thirty days would be spent at Mars.

The conjunction-class mission is 910 days in total with 180-day trips to and from Mars and a stay at Mars of 550 days before the return window opens. The Hohmann trajectory and the 180-day trips mentioned all involve traveling about 141,101,000 miles each way. The 430-day outward trip of the opposition-class mission would involve about a 417,000,000 mile trip to Mars.



The technical, physiological and psychological aspects of any human flight to and from Mars are under intense study as there is essentially no empirical evidence for any human space flight of this type and duration. Risks of equipment failure, fuel leakage, repair capabilities, crew absorption of solar and galactic radiation, crew autonomy and a 20-minute communication lag each way from Mars to earth, isolation in a confined space over months or years, psychological breakdown, health and injury issues that may arise, and re-entry when arriving back at earth.

Radiation absorption is a major concern. The radiation on the International Space Station is 60 times greater than on earth, the radiation in space is 250 times the earth level, and the radiation on the moon or Mars is 83 times earth level. Those on the ISS receive a year’s worth of earth radiation every six days. The number for the moon or Mars is every 4 days. The number for deep space travel is every 1.5 days.

This means that the radiation received on the ISS in one year is equivalent to that received over the course of 60 years on earth, and the radiation received in deep space over one year is the equivalent of 250 years on earth. A year on the moon or on Mars is equivalent to 83 years of radiation on earth.

For a 2 ½ year conjunction-class round-trip to Mars the crew would receive at least 625 years' worth of earth radiation.

As a final note, let me quote Arthur C. Clarke from his 1950 book Interplanetary Flight, page 71, on what is required to make a direct flight to Mars or some other planet.

If almost unlimited energy sources were available, it would be possible to travel from one planet to another in very nearly a straight line. The velocities required in this case would be of the order of a hundred kilometers a second, and the transit times to Mars or Venus would be less than a week.

For perspective, one hundred kilometers per second times 60^2 = 360,000 km/hour and 360,000 x 0.621 = 223,560 miles per hour. This is about 64 times faster than the average velocity of the Apollo missions to the moon, which was about 3,500 mph.

Getting People Back to Earth

As for returning people back to earth, this is no easier than sending people up into orbit or beyond.

The strong gravity well of earth has to be countered in some way to slow any craft for a landing. And while earth's thick atmosphere is helpful in slowing a vehicle, it also applies extreme friction generating enormous heat. This heat has to be absorbed, displaced or dissipated in some way. Heat shield tiles are used to absorb and dissipate the heat, shielding the people and instruments inside the returning vessel. Any passengers experience from 3 to 5 g's as the returning craft or capsule slows down as it travels through the dense earth atmosphere.

Nothing has changed since the Apollo program. Three to four people return to earth aboard a small capsule engineered to withstand the heat generated by the rapid fall to earth through the dense earth atmosphere until parachutes can be deployed to soften the landing to 17-20 mph, either landing on the land like Russia's Soyuz or splashing down in the ocean like the Falcon 9 dragon capsule and the new Orion crew capsule.

Blue Horizon's New Shepard rocket has propelled its own capsule, with Jeff Bezos and five others aboard, 66 miles above the earth. The single booster rocket fell back and landed under its own power on earth and the capsule fell back to earth slowed by three parachutes and a quick last-second power blast to soften the landing on dry land after 10 minutes aloft.

For a number of years, the Space Shuttle, with from 8 to 10 aboard, offered an alternative that looked more like an airline but landed as a glider without power. It only used a bit of power to slow down in orbit after releasing from the ISS and then began its drop to earth under the force of gravity, ultimately landing like an airplane without operating engines.

SpaceX is seeking to bring its upper stage of Starship back to earth through earth's atmosphere and land on earth under power, ultimately carrying up to 100 passengers on board. The fierce journey through the atmosphere is the biggest obstacle.

All current return capsules fall rapidly to earth under the force of gravity and employ heat shield tiles on the most vulnerable parts of the capsule to ward off the fierce heat of reentry through the atmosphere at very rapid speed. The second stage of Starship seeks to use a similar heat shield technology when falling toward earth on its huge underside, essentially belly-flopping its way through the atmosphere. Heat shield technology has proven effective for small return capsules carrying three or four people. The larger space shuttle, carrying up to nine people, was found to be expensive and problematic. Whether the large Space-X Starship carrying 100 people or more can be successful remains an open question.

An alternative cooling mechanism has been built but not yet tested in space by Stoke Space. The second stage autonomous orbit-payload rocket uses circulating liquid hydrogen to cool a stainless steel rocket base, which will face the fierce heat of reentry. It is designed to be rapidly reusable for quick turnaround for earth orbit missions. The whole system is designed to be a reusable and rapid turnaround system for orbital delivery and recovery missions.

There remains no simple way to return large numbers of people to earth.

It requires just as much thrust per kilogram of mass to return to earth gently without damage to the spacecraft or to the passengers as it takes to lift off and travel to earth orbit. Given that rockets are currently about 90% fuel at liftoff, this means that a returning rocket must consist of at least 90% fuel. A returning spacecraft with a mass of 100,000 kilograms would require about 90,000 kilograms of fuel to power itself down to earth gently and avoid overheating in passing into and through earth's atmosphere. Current rockets nearly use up their load of fuel getting into earth orbit. If a spacecraft had traveled to the moon or Mars and returned, it seems clear that it would have to be resupplied with fuel in earth orbit before it could attempt to use power to slow its descent to earth for a safe landing. This is not the sort of thing that you see in Star Wars or other space movies! There, spacecraft seem to have unlimited power supplied somehow by perhaps 1% of the ship's mass. At present this is impossible. And it may always be impossible.

Moving on to Space Travel

We have so far just looked at the issues of getting off the earth, traveling to the moon, returning to earth, and getting back on land or in the sea. The problems and expenses involved for these tasks are daunting but pale in comparison to the problems of space travel beyond the moon.

C: Limits to Human Space Travel: Distance, Speed and Biology

Three Limitations to Human Space Travel

The elements limiting human space travel are distance, the universal speed limit along with other principles of special relativity, and the biology of life.

Distances in space are enormous.

The speed limit built into the universe, the speed of light, puts a stop sign in front of all dreams of interstellar and inter-galactic travel. The strange effect of mass dilation stops any attempt to reach light speed. And time dilation, while it slows time for the crew traveling at near light speeds, also separates the crew from their cohort on earth as earth ages at its normal rate. At very high rates of speed the earth cohort would age and die before the crew returned to earth.

Biology and our dependance on the complex microbial ecology of earth presents another daunting impediment to space travel.

Section I, Distance: The Fathomless Distances of Space

On earth we may drive at 60 miles per hour. Traveling a distance of 200 miles by car is a good long trip. We have developed airplanes that can cross the U.S. from coast to coast in about 5 ½ hours. For example, a trip of 2,415 miles from SEATAC in Seattle to JFK airport in New York City travels at 439 mph. These examples give our current normal human understanding of time, distance and speed.

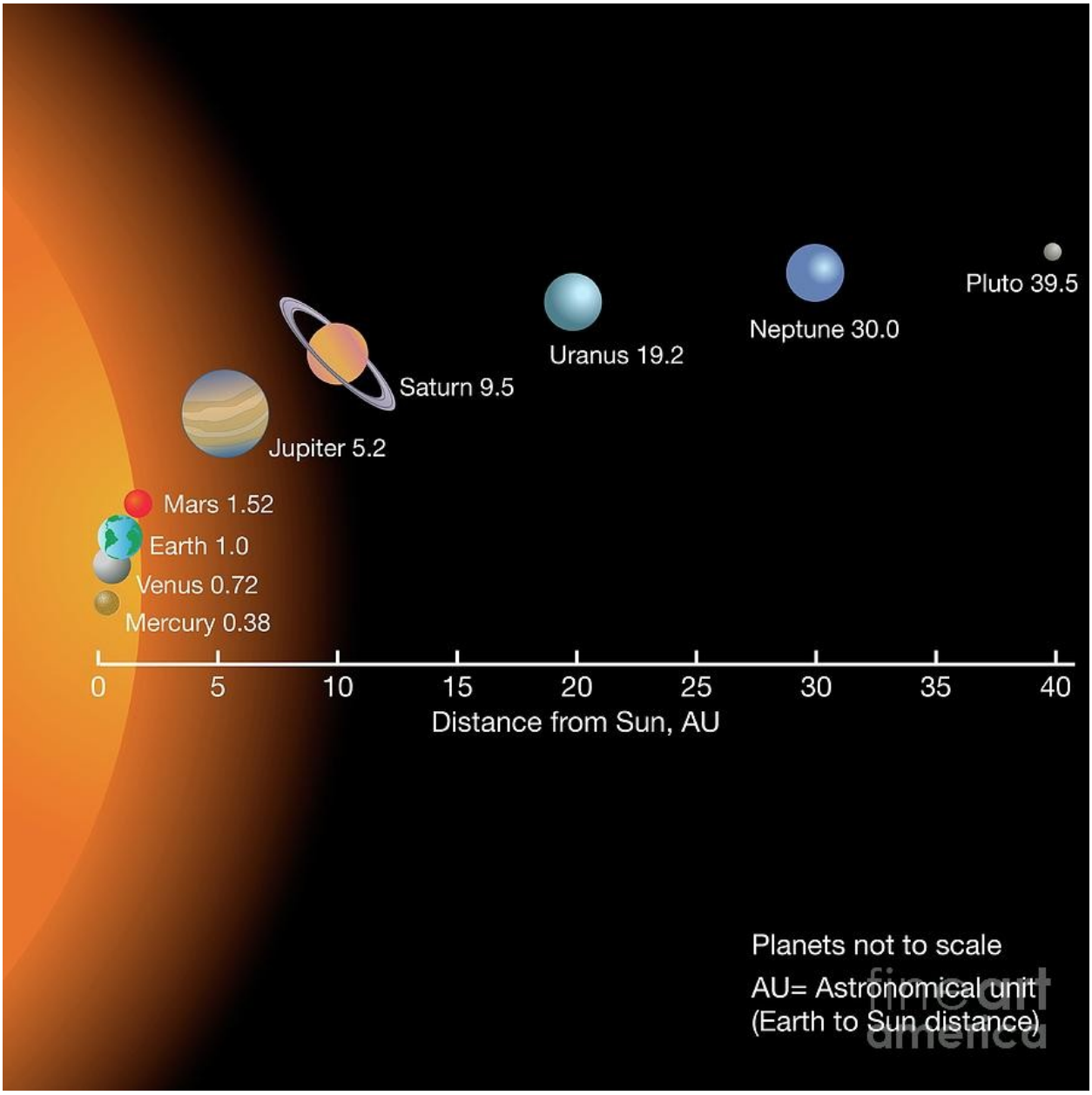
Distance in space beyond earth is very different.

Our moon, the nearest body in space to the earth, is at a distance of 238,900 miles. Three humans traveled there in 68 hours on the Apollo 11 mission in 1969 at an average speed of 3,500 mph. The total mission from earth to moon and back lasted 8 days and about 3 ½ hours, including almost one day (21 hours and 36 minutes) that two astronauts spent on the surface of the moon.

Within our solar system, there are four inner planets of which earth is one. Venus is our nearest neighbor planet at 24,800,000

miles at its closest, about ten times more distant than our moon. Next nearest is Mars at 35,000,000 miles at its closest. Then comes Mercury, 48,000,000 miles distant at its closest.

The four outer planets of our solar system are more distant, starting with Jupiter at 365,000,000 at its closest. Then Saturn, 746,000,000 at its closest. Next comes Uranus, 1,600,000,000 at its closest. And last is Neptune, 2,700,000,000 miles distant from earth at its closest. Neptune is about 10,000 times more distant than our moon is from earth and about 1,000 times more distant than Mars is from the earth.

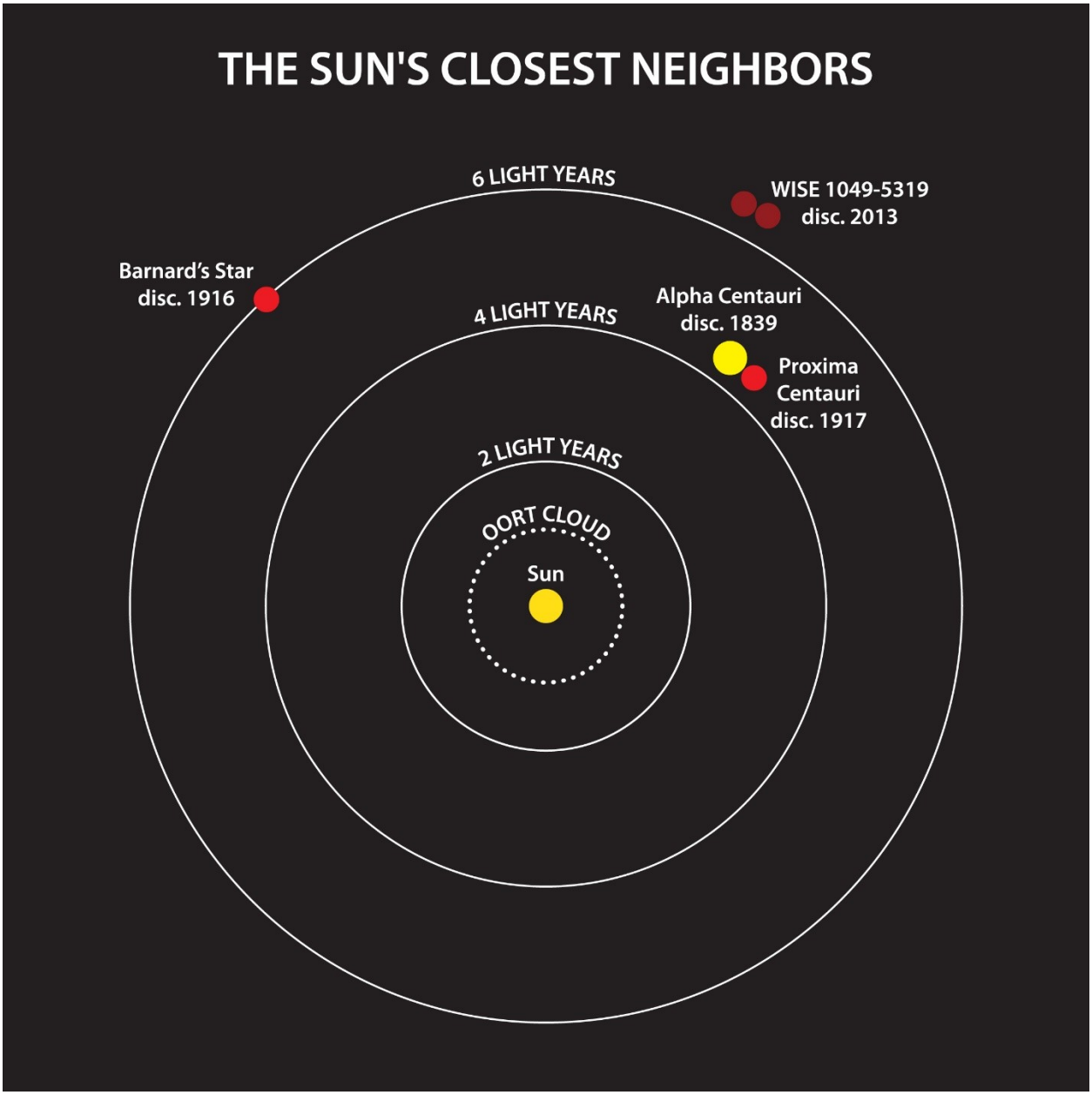


Also, traveling in space in a straight line path to our destination would require enormous amounts of energy. And our destination planet is moving all the time, as earth is, so that we have to aim for where the planet will be in the future not where it is today. We have to travel in an indirect, curving path to conserve fuel. In the case of Mars, which may be 35,000,000 miles away in direct distance at its closest, we have to travel 141,101,000 miles on the Hohmann Transfer Orbit at an average velocity of 21,500 miles per hour, using the least fuel possible and the one-way trip

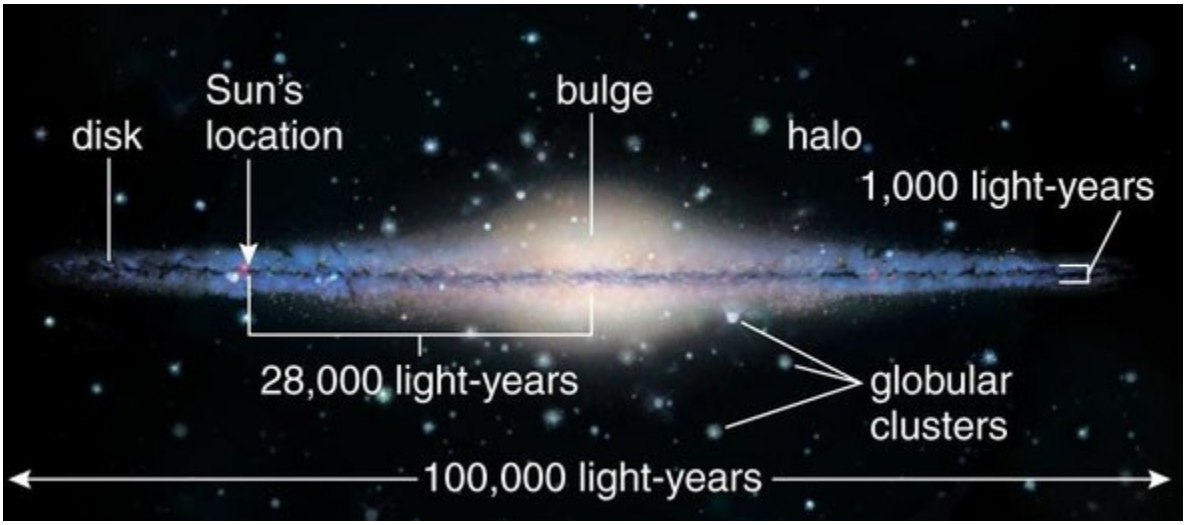
is expected to take nine months of travel time. Then our astronauts will have to wait 26 months for another window of opportunity to make a similar return flight, for a minimum of 44 months round trip or nearly two years.

NASA is proposing a crewed trip to Mars in 2035 with a nine-month one-way travel time using the Hohmann Transfer Orbit. This works out to about 21,760 mph average speed for a trip of 141 million miles. This speed is more than ten times the average speed of the Apollo missions to the moon. NASA is talking about using a nuclear fission-thermal engine for this trip. The nuclear fission plant provides heat while using little fuel; liquid hydrogen or even water might be the actual fuel exhausted by the engine after being heated by passing it through the nuclear power plant, providing thrust.

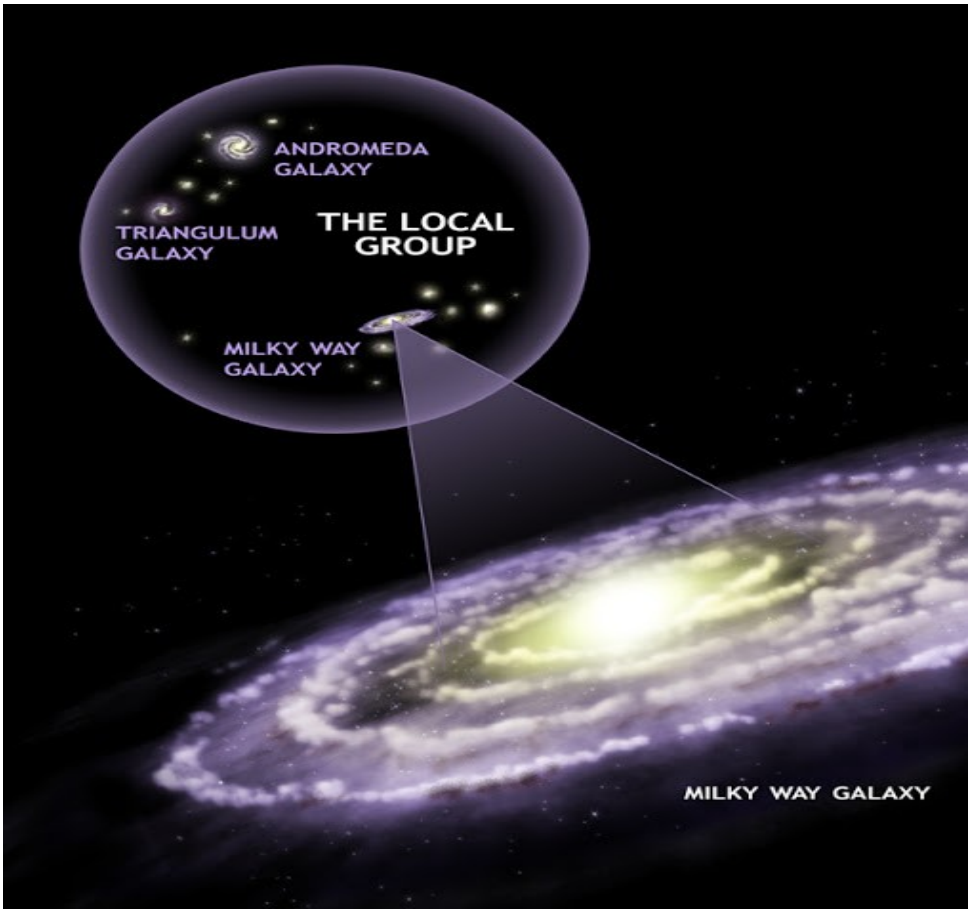
Our nearest neighbor star is Proxima Centauri, a red dwarf or burned-out star, at 24,600,000,000,000 (24.6 trillion) miles distant from our sun. Proxima Centauri does have a planet circling it in the habitable zone. This is 4.2 light years away. Next is Alpha Centauri, a binary star system, two stars circling each other, at 4.4 light years, a poor prospect for planets habitable by life. Next up is Bernard’s Star at 6 light years distance. Bernard’s star might have planets and might be worth looking at, but even at 21,500 mph average speed our ship would require more than 187,000 years to get there.



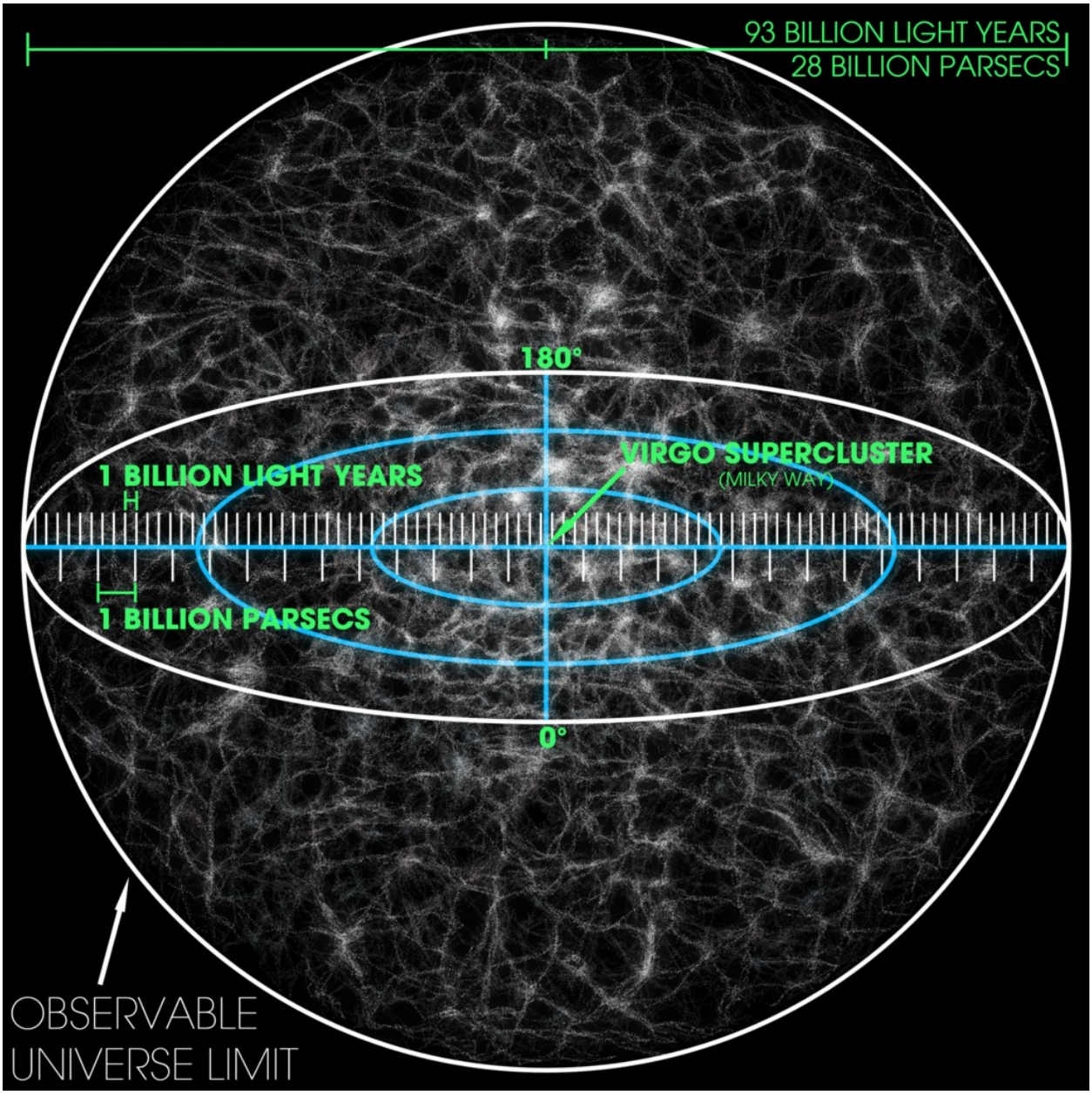
Next, consider our Milky Way galaxy. It is a spiral galaxy about 100,000 light years across and has a central bulge that is about 1,000 light years deep. Obviously, we can never reach any of the billions of stars in our own galaxy or visit any civilizations that might inhabit planets in their solar systems while traveling at 21,500 mph.



Now consider the nearest galaxy to the Milky Way, part of what is called the Local Group. The nearest galaxy in the Local Group is LMC (Large Magellanic Cloud) which is 0.16 million light years distant from the Milky Way. Within the Local Group the galaxy furthest away from us is the Pinwheel (M33) galaxy at 2.77 million light years.



Beyond the Local Group, a few of the endless galaxies are the Sombrero galaxy at 28 million light years, the Whirlpool at 37 million light years, the Tadpole at 420 million light years and the Hoag's Ring galaxy at 600 million light years distant from the Milky Way. We can visit none of these galaxies, even traveling at light speed. The distances are just too great.



The universe is estimated to be 13.8 billion years old. Early galaxies are believed to have formed more than 13 billion years ago, based on observations by astronomers. That is a lot of time in which technological civilizations may have arisen and disappeared on planets in solar systems around stars in uncountable galaxies. The universe has been expanding during all this time. Each location in space has its own observable universe. Earth's current observable universe is a circle with a diameter of 93 billion light years. The unobservable universe is

estimated to be perhaps 250 times larger and may possibly be unmeasurably large. We will not be visiting any of the galaxies throughout this great expanse.

So much for distance.

What about speeding up our spacecraft?

Section II, Speed and Special Relativity Effects

The Universe's Speed Limit

Since Albert Einstein published his special relativity paper in 1905 we have known that the universe has a speed limit built into it. This limit is the speed of radiation, of which light is the most obvious. The speed limit is 186,000 miles per second, 669,600,000 mph or 5.866 x 10^12 miles per year. This last number is known as a light year.

While the speed of light is very fast, the enormous distances of the universe are even greater.

The universe is 13.8 billion years old, going back a distance of 13.8 billion light years or 8.1 x 10^22 miles to the Big Bang, with galaxies existing for at least 13 billion years. This is the deep time and distance over which life and civilizations may have arisen and disappeared. Our nearest neighbor galaxy, the LMC or Large Megallanic Cloud, is about 160,000 light years or 9.4 x 10^17 miles distant from us. Given this speed limit, distance is one major impediment to space travel.

But special relativity adds two more impediments.

The first is that only objects such as photons, or light rays, that are born traveling at light speed, can ever reach this speed. Material objects that are not born traveling at light speed cannot ever reach this speed. Special relativity tells us that mass, which is the resistance to change of speed or direction, is affected by acceleration. The faster we push a material object, such as a spacecraft, the greater is the resistance to further pushing. This means that more and more energy is required to push a

spacecraft to higher speeds. At the speed of light, the energy required goes to infinity. So, we can never have enough energy aboard a spacecraft to push it to the speed of light. There is an energy-speed tradeoff.

The second impediment is that when our space travelers reach speeds of 90% or more of the speed of light, if they could ever reach this velocity, time begins to seriously slow down for them relative to their fellow humans residing back on earth. The formula for this effect is

$$\sqrt{1-\left(\frac{speed\ of\ spacecraft}{speed\ of\ light}\right)^2}$$

At 90% of the speed of light, this difference is the square root of 1-(1/.9)^2 or .436 (43.6%). This means that on earth after one year passes, time has advanced only .436 year for those aboard the spacecraft. Or, stated the other way around, if one year passes for the astronauts, those on earth age by 1/.436 or 2.3 years, using the following formula.

$$\frac{astronaut's\ aging}{\sqrt{1-\left(\frac{speed\ of\ spacecraft}{speed\ of\ light}\right)^2}}$$

The effect becomes greater as one approaches the speed of light. At 99% of the speed of light, time aboard the spacecraft slows to .141 or 7.1 to 1 ratio of time passing on earth versus time passing on board the spaceship. At 99% of the speed of light, if our spacecraft returns to earth after ten years of travel they will find that earth time has advanced nearly 71 years. This effect grows greater at even more advanced speeds. So, if our spacecraft could be accelerated to close to light speed and then return to earth, earth would not be anything like the place we left

earlier. At 0.999 light speed, earth would age 224 years while the travelers aged 10 years, a 22.4 to 1 ratio. At 0.9999 light speed, the ratio is 707 to 1 and earth ages 7,070 years to the travelers 10 years.

Speed In Space

The proven speed of human space travel, provided by the Apollo 11 (1969) trip to the moon and other Apollo missions, is a maximum speed of nearly 24,500 mph (earth's escape velocity) and an average speed for the trip to the moon of 3,500 mph as earth's gravitational pull gradually slowed the craft.

Acceleration of a human spacecraft must be kept at or below five times earth's gravity and then for only very brief periods of time for human safety, according to the current scientific consensus. The highest Apollo 11 force was nearly 4g lasting less than one minute and came while escaping from the hold of earth's gravity. Six times earth's gravity will kill humans. Jet pilots have survived nano-second moments of up to 11 g. Once in space, acceleration can proceed at one g, the level of earth's gravity with safety and comfort for humans. However, carrying enough fuel for any acceleration in space quickly becomes a problem even at the level of 1g continuous acceleration.

A Strange Effect: Mass Dilation Near Light Speed

The mass of the ship plus fuel increases as the ship approaches light speed. Mass is a measure of resistance to further acceleration. As the mass increases, it will take more and more fuel to push the spaceship to higher speeds. The mass increases toward infinity as light speed is neared so that no space ship can ever achieve light speed. The only objects that achieve light speed are born already traveling at light speed, such as photons generated by the sun.

The formula for this effect was outlined by Albert Einstein in his Special Relativity theory in 1905.

$$\frac{Mass}{\sqrt{1-\left(\frac{speed\,of\,spacecraft}{speed\,of\,light}\right)^2}}$$

In words: mass divided by the square root of 1-(the speed of the spacecraft / the speed of light) squared.

If the ship plus its fuel is a mass of 100,000 tons and the speed of the spacecraft is 90% the speed of light, then the mass increases by a factor of

$$\frac{Mass}{\sqrt{1-(0.9)^2}}$$

= 2.29 to 229,000 tons for 90% of light speed, requiring more than twice as much energy to push the craft to higher speed.

If the speed of the spacecraft is 0.999 of the speed of light, then

$$\frac{Mass}{\sqrt{1-(0.999)^2}}$$

= 22.37 X 100,000 tons = 2,237,000 tons, more than 22 times as much energy is required.

So, our spacecraft and its load of fuel can never reach light speed or carry enough fuel to approach close to light speed using current propulsion methods and fuels.

Another Strange Effect: Time Dilation Near Light Speed

Near light speed, time slows down for a space crew traveling from earth.

Assuming that we could reach close to light speed, say 99.9%, this is another dilemma for the crew on the ship.

If the round trip took 10 years at 99.9 of light speed, the crew would naturally age 10 years. But when they returned to earth they would find that the earth and everything on it had aged much more than 10 years.

The number of years aging on earth would be

$$\frac{Astronaut's\ aging}{\sqrt{1-(0.999)^2}}$$

10 / .04471 = 223.7 years. The astronauts would find the earth entirely changed and their acquaintances all long dead.

The Photon Rocket

The ultimate propulsion system for space travel optimists is a photon rocket because it would increase the exhaust velocity to the maximum possible, the speed of light. It is not forbidden by physical law, but it may be forbidden by practical engineering. It represents the outer extreme solution for achieving the speeds needed for the simplest interstellar flight.

The photon rocket would use matter-antimatter annihilation to generate 100% energy from matter and thus reduce the amount of fuel matter needed to the minimum possible. The photon rocket would direct the energy thus created in precisely the opposite direction that the rocket wishes to move to take full advantage of the conservation of momentum. The equation E = mc^2 tells us that enormous amounts of energy are contained within a tiny amount of matter and that under the right conditions a conversion can be made from matter to energy or vice versa. Bringing together matter and antimatter would achieve a 100% conversion of matter to energy. The resulting radiation energy would, in the optimists' view, exhaust from the rocket in a directed fashion at the speed of light in the form of photons. And since the Rocket Equation depends critically on the exhaust velocity, this will minimize our spaceship's fuel requirements.

Photons have no mass but they do have momentum, which is equal to their energy divided by c, the speed of light. Each photon has an effective mass of 0.61 x 10^-32 kg based on e = mc^2 because mass = energy/c^2. Because the exhaust of photons has momentum, the ship reacts with the same momentum in the opposite direction. This is a miniscule amount of momentum. Typically, matter-antimatter reactions emit two photons and this means a very large amount of fuel would be required to supply enough photons to generate any meaningful momentum.

We will assume that all the engineering issues have been settled and we have a photon rocket engine. We will use the Starship HLS module for an example scenario of making use of this photon rocket engine. And we will assume that we wish to make a trip to our nearest star, Proxima Centauri, at 4.2 light years distance, and visit the planet called Proxima Centauri b, located in the habitable zone of its star. Further, we will assume that we wish to attain a velocity no greater than 30% of light speed or 0.3c to keep the effects of mass and time dilation below 5%. We can now calculate the Rocket Equation to see what our fuel needs are to achieve a velocity of 0.3c.

M_i / M_f = $e^{(\frac{0.3c}{c})}$ = 1.3498... or approximately 1.35.

Since we plan to accelerate to a speed of 0.3c, decelerate to stop at our destination, travel around a bit, then accelerate to head back home to earth and decelerate to stop at earth, we need to take 1.35 to the power of 4 which gives us 3.32 for the mass ratio for the whole round trip.

This calculation uses the standard non-relativistic Rocket Equation to determine the fuel needs for the trip. But, since the exhaust velocity is at light speed and most of the trip is made at 30% of light speed, the relativistic rocket equation should be used to establish the fuel needs. The equation looks like this.

$$M_i \,/\, M_f = \left[\frac{1 + \frac{delta\ V}{c}}{1 - \frac{delta\ V}{c}} \right]^{\left(\frac{c}{2\ Ve}\right)}$$

where: delta V = the desired change in velocity

c = the speed of light and Ve = the rocket exhaust velocity.

Our calculation using this equation is simplified by setting c = 1. Then delta V is .3 and Ve is 1. So, we have (1.3/.7)^(1/2 x 1) = 1.857^(1/2) = 1.363. This raised to the power of 4 gives us the overall mass ratio of 1.363^4 = 3.45.

This result, we can see, is a bit higher than the non-relativistic calculation of 3.32 for the overall mass ratio of the trip.

Now consider our spaceship. The proposed HLS has about 250,000 kg unfueled weight with a crew of up to 100 people and a fuel capacity of 2,600,000 kg.

Now we need to determine our fuel needs for a trip to Proxima Centauri and our return to earth. Taking 3.45 x 250,000 kg gives us 862,500 kg, which means that we need 862,500-250,000 or 612,500 kg of fuel, well within the fuel capacity of the HLS spacecraft. We will assume that we take 1,000,000 kilograms of fuel, giving the ship a total mass of 1,250,000 kg. The extra space in the ship not used for carrying fuel may be used as additional living space.

We further plan to accelerate and decelerate at 1 g, the value of earth’s gravity for the comfort and safety of the crew. At this rate of acceleration, it will take 107 days to reach 0.3c velocity. The velocity goal in meters divided by the acceleration rate in meters equals the seconds required. We use here the formula t (s) = v (m/s) divided by a (m/s^2). We calculate 0.3c = 90,000,000 m/s divided by 9.8 (m/s^2) and get 9,183,673 (s). Converting seconds into days gives us 107. During acceleration the crew will feel a pull equal to earth’s gravity. After the engine is shut off

and the ship begins to coast toward its destination, however, the crew will experience a gravity-free environment similar to that experienced on the International Space Station. This period will last 13.7 years, with unknown effects on the crew. This might also be an incredibly boring time.

As the spacecraft nears Proxima Centauri thrusters will turn the ship around and then the photon engine will begin firing to decelerate at 1g, ultimately bringing the spacecraft to a halt at its objective. Now the spacecraft can navigate its way to Proxima Centauri b, perhaps also using thrusters, to begin investigating the planet. The crew will examine this planet, the star Proxima Centauri and the rest of its solar system for the next six months. Then the spacecraft will navigate to an exit position and begin its return trip to earth, first accelerating for 107 days to achieve 0.3c velocity again. Then begins the long and boring coasting ride taking 13.7 years in a gravity-free environment. Then the spacecraft reverses itself and begins firing the photon engine to decelerate and finally stop near earth after another 107 days.

Here is a summary of the trip.

Distance (light years)	Time (crew years)	Speed (avg. mph)	Comments
0.044	0.3	100 million	acceleration
4.112	13.7	201 million	coasting
0.044	0.3	100 million	deceleration
0	0.5	0	exploring

0.044 acceleration	0.3	100 million	
4.112	13.7	201 million	coasting
0.044 deceleration	0.3	100 million	
8.4	28.6	197 million	total travel
0	0.5	0	study time
n/a	29.1	n/a	total trip

Aging of the astronauts was 29.1 years.

Aging on earth was $\frac{Astronaut's aging}{\sqrt{1-(0.3)^2}}$ = 30.5 years.

This is the best-case travel scenario for the best-case propulsion scenario. It will take us to our nearest star and back again to earth. And it will take 29 years out of our astronauts' lives.

Compare this to our present accomplishment. In the 1960s and 1970s humans traveled in space for eight days to the moon and back, traveling at an average speed of 3,500 miles per hour.

Perhaps the most shocking thing about our photon rocket scenario is that our astronauts spend more than 27 years of their productive lives in the boredom of coasting through space at 200 million miles per hour in a weight-free environment. If a 17-hour airplane flight on earth seems tedious, imagine extending the journey to 27 years and doing it in a weight-free environment.

But if our spacecraft had traveled at 90% of the speed of light, the fuel requirement would have risen by 82% to 2,500,000 and it would have required 319 days of acceleration to reach our speed objective. Our time spent coasting would have been reduced to about 2.2 years each way, cutting the total trip to about 8.9 years

astronaut time while earth would have aged 20.4 years. This 11.5-year difference would be more noticeable than the one-year difference in aging in our 0.3 light speed scenario.

Thus, even with a perfect photon rocket, we can only reach our nearest star and return within a human lifetime. And if we could reach close to light speed for our travel, if we did return, we wouldn't recognize the earth or find our friends still there to greet us. Time travel is theoretically possible, but it is only one way; space travelers can go into earth's future, but they can never return to earth's past. This doesn't bode well for a future of hob-knobbing with other beings throughout the galaxy, as science fiction stories suggest. And these other beings are in no better position to hob-knob with us, for they face all the same problems of space travel that we do, including one-way time travel.

As V. Smilga concluded in his 1960 article "THERE WILL BE NO PHOTON ROCKET", which was widely circulated among U.S. military and scientific agencies at the time, "Something unknown is needed. Something as unknown as the atomic power station was to Pithecanthropus."

Interstellar Travel Using Time Dilation

In my generous scenario of a trip to Proxima Centauri and back to earth the trip at 30% of the speed of light took 28.6 years in travel time. If we must content ourselves with non-relativistic speeds, then the trip would take more than a human lifetime in the best of circumstances.

Some people say that by traveling at near light speeds we could reach the edge of our galaxy in 12 crew years. That would involve traveling 50,000 light years or about 3 x 10^17 miles in 12 years. How can this be? Well, we already learned that crew time slows down at near light speeds. So, the only question is: how fast would the crew need to travel to accomplish this feat? The equation for this is:

$$\sqrt{1-\left(\frac{speed\ of\ spacecraft}{speed\ of\ light}\right)^2}$$

We want to know the speed of the spacecraft. Experimenting with numbers, I found that our crew would need to travel at about 0.999999971 c. A good talking point but not very realistic since the relativistic rocket equation tells us how much fuel this would take:

$$M_i \,/\, M_f = \left[\frac{1+\frac{delta\ V}{c}}{1-\frac{delta\ V}{c}}\right]^{\left(\frac{c}{2\ Ve}\right)}.$$

[(1 + 0.999999971)/(1 – 0.999999971)]^(1/2) = 5,872.

We would need a fuel-carrying ship 5,872 times larger than our crew-ship. And, if we wanted to stop at the edge of the galaxy, this number is 5,872^2 or 34,480,384. If we wanted to return to and stop at earth this number would rise to 5,872^4 or 1.2 x 10^15.

And if we did return to earth, adding 12 more years to the crew's age, how much time would have passed on earth? The answer is

$$\frac{Astronaut's\ aging(24\ years)}{\sqrt{1-(0.999999971)^2}}$$

which equals 99,654 years. In other words, earth aged 100,000 years while the flight crew aged only 24 years. What kind of earth would the crew find when they returned?

Time travel is possible, but only into the future. No return from the future is possible.

Intergalactic Travel Using Time Dilation

How long would it take this same crew to continue on to visit our nearest neighbor galaxy, Andromeda, which is 2.537 million light years distant? It would take about 51 times longer (2,537,000/50,000). Twelve years x 51 equals 612 years. So,

even with this extreme use of time dilation, which is not practical for energy reasons, the crew would be long dead before the ship reached our nearest neighbor galaxy. And the billions upon billions of other galaxies in the universe located at even more distant locations are obviously even further out of reach.

What If We Could Travel Instantly Through Both Space and Time?

Could we or some beings from another world locate and visit other technological civilizations if it were possible to travel instantly through both space and time?

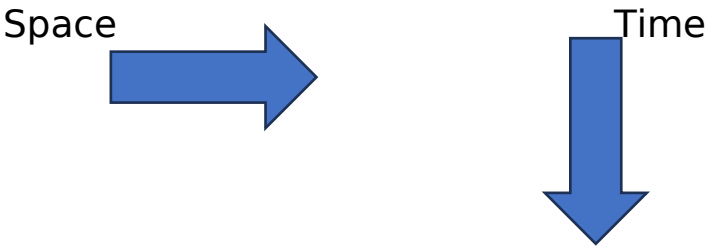
We have seen that the universe is enormously large, with unfathomable numbers of galaxies, stars and planets which might support life and even technological civilizations at some time during their existence. We have also seen that the stars and therefore solar systems within a galaxy are separated by multiple light-year distances.

But waving aside the challenges of traveling in deep space, let us say that we can instantly travel to any planet in any solar system in any galaxy we may choose, picking one that is in a suitable habitable zone around its star. Now we have the problem of deep time. We will need to become travelers in time as well as space.

Using earth as our example, we know the planet formed about 4.6 billion years ago, with life beginning about 4 billion years ago and animals evolving about 600 million years ago. Further, we know that we humans evolved one or two hundred thousand years ago. Continuously recorded time began just 5175 years ago in Egypt (as of 2025 CE). And we have had a technological civilization for about 100 years with electricity, the use of petroleum, radio and television signals and rocket science. Our technological civilization has existed for about 100/4.6 billion of the planet’s existence, a miniscule period of earth’s existence.

When arriving at a likely planet we, or our travelers/researchers, are faced with a dilemma. It is an extremely remote possibility that we, or they, have arrived at this planet at just the brief moment in time when a technological civilization currently exists.

So, now we must use time travel to seek our objective. We must sample the planet at times in the past and/or in the future depending on when the planet formed and when in its history we arrived there.



Our travelers/researchers need to decide on some sampling technique. Had they arrived at earth one million years ago, they would be faced with a search time frame of perhaps 500 million years in the past and 500 million years in the future. If they estimate the lifetime of a technological civilization at 500 years, then they might choose this as their sampling window, stopping every 500 years to look at the planet, perhaps taking one day of their life to perform each sample. With one billion years to cover, this requires two million sampling periods or stops in time. And at one day per sampling period that amounts to two million days or nearly 5,500 earth-years out of their lives. They had better have very long lives. And this is just to examine one planet.

But, if they are mistaken about the length of life of a technological civilization being 500 years when it is actually only 200 years, then they could easily miss finding a civilization using their 500-year sampling window. They could fly right past it in time. But reducing the sampling window would greatly increase the time required for the survey. Surely our travelers/researchers don't have such time available to them.

Thus, even accepting the possibility of unlimited space and time travel there is virtually no chance of one technological civilization finding and contacting another. Finding a needle in a haystack would be easy by comparison.

<u>Science Fiction and Science Fact</u>

In science fiction books or films, the ratios of the propellant mass, structural mass and payload mass of spaceships are turned upside down from what exists in reality.

The Saturn V/Apollo 11 relationships were propellant mass 89%, structural mass 10% and payload mass 1%. These ratios for chemical rockets have not changed.

But, in the case of the Millenium Falcon ship in the Star Wars movies, the relationships are propellant mass 1%, structural mass 89%, payload (beings, instruments and weapons) mass 10%.

In the case of the Empire's small one-pilot Tie Fighters, the relationships are propellant mass 0% (because the Tie Fighter has twin ion engines powered by solar panels, seemingly powered even when there is no sun around!), structural and weapons mass 99%, and payload (one being and instruments) mass 1%.

These science fiction ratios are completely unrealistic.

Also, the rapid course-changing flight of each of these space vehicles is contrary to what is possible in outer space. These science fiction spacecraft rapidly change course like jet aircraft pushing against the dense atmosphere of earth. In atmosphere-free space, this is not possible.

Course changes in space are slow and gradual.

And flying inside deep gravity wells that surround planets, as some of these spacecraft do, would require enormous expenditures of energy, not evident in the movies.

Science Fact and Rocket Thrust

Rocket thrust, kg x m/s^2, consists of an exhaust velocity, m/s, created by the energy of the fuel times a mass ejection rate, kg/s, of the propellant material.

As a general rule, the energy source and the material ejected are the same, such as a mixture of liquid hydrogen, LH2, and liquid oxygen, LOX, with the combustion cycle started with energy provided by an electric or chemical "spark".

If a nuclear plant is used, however, this could supply the energy to drive the exhaust velocity while liquid hydrogen or even water, H2O, might supply the mass ejection material, superheated by running it past the hot nuclear plant.

The objective and result of exhaust velocity x mass ejection is momentum, kg x m/s. Thrust, kg x m/s^2, is momentum per second. And since momentum is a conserved quantity, the momentum of the propellant ejected creates an equal and opposite momentum to push the rocket ship forward.

For an equal amount of thrust one could have a low exhaust velocity paired with a high rate of mass ejection or a high exhaust velocity paired with a low rate of mass ejection. And since one objective is to keep the mass of the rocket to a minimum, since greater mass requires greater thrust to move the rocket ship, one major goal is to increase exhaust velocity.

When using chemical fuels for both the energy to drive exhaust velocity and for mass ejection, as Clarke writes (p. 81), “efflux velocity decreases as the molecular weight of the gases increases”. Thus, the lighter chemicals, and H2 is the lightest, provide the highest rates of exhaust velocity and mass ejection, and thus the most thrust.

For chemical rocket engines, a measure of the engine efficiency in the use of fuel is the specific impulse or Isp. Isp is defined as the exhaust velocity, Ve (m/s), divided by earth gravity at sea level, g (m/s^2), which results in units of seconds (s). So, thrust is equal to g x Isp, with the result in m/s, times the mass ejection rate (kg/s) resulting in kg x m/s^2. And exhaust velocity, Ve (m/s), equals earth gravity at sea level times the specific impulse, Isp (s), or Ve = g x Isp. A higher Isp implies a higher exhaust velocity.

However, since thrust equals exhaust velocity times the mass ejection rate, the mass ejection rate is also critical if high thrust is required, as it is when a rocket seeks to lift off from earth by overcoming earth’s gravitational pull. The thrust required to

overcome earth's gravitational pull is 9.81 x the mass of the rocket. For example, the Saturn V rocket had a mass of about 3,000,000 kilograms. This multiplied by 9.81 equals 29,430,000 Newtons of thrust (kg x m/s^2) required just to offset earth's gravitational grip. More thrust was needed to actually lift the Saturn V rocket off the earth. Typically, rockets use another 20% or more of thrust to lift a rocket off the earth.

In deep space, away from any significant gravitational influences on very long trips, the amount of thrust and acceleration is less critical, and a low mass ejection rate would be more tolerable. However, rapid acceleration, deceleration or changes of course would be impossible.

Movie images of spacecraft showing rapid acceleration, deceleration or changes of course violate fundamental scientific principles and can't happen in reality. The energy required for such maneuvers is impossible within current scientific knowledge.

Take the Millenium Falcon spacecraft in the Star Wars movies, for example. Let's estimate its mass as 200,000 kilograms of which 100,000 is available for storage of fuel. Let's assume we have to use known chemical fuels. This leaves the permanent Falcon, the ship less fuel, at 100,000 kilograms. Now, let's say our velocity goal is 10 km/s (equal to 26,364 miles per hour) and our exhaust velocity is 5 km/s (a generous value for a chemical rocket engine). Using the Rocket Equation, Mi (total mass)/Mf (mass of ship less fuel) = e^(Vgoal/Ve) or Mi/Mf = e^(10/5) = e^2 = 7.4. This means the Falcon needs a total fueled mass required of 7.4 x 100,000 kg or 740,000 kg. Subtracting the ship mass gives a fuel requirement of 640,000 kg, far more than the 100,000 kg capacity of the Falcon. And this is just to accomplish this one maneuver of accelerating to 10 km/s. Decelerating to a stop would require not twice as much fuel but (e^2)^2 = 54.6. This, in turn, means 53.6 x 100,000 kg or 5,360,00 kg of fuel is needed. This is because we need much more fuel to provide the thrust needed to move a greater amount of fuel. The huge amount of

fuel needed becomes an exponentially growing problem with every additional maneuver the ship needs to make.

Obviously, the Millenium Falcon cannot carry enough chemical fuel to perform any of the maneuvers it displays in the Star Wars movies.

Although separating exhaust velocity energy from the mass being ejected has been achieved with ion plasma engines using electricity generated by solar panels to dislodge electrons from some material and exhaust the electrons at very high speeds (20,000 to 80,000 m/s), the tiny mass embodied in the electrons ejected only generates about 100 Newtons of force. By division, this means the mass ejection rate is 100 (kg x m/s^2)/20,000 (m/s) or 0.005 kg/s, or less if the exhaust velocity goes up to 80,000 m/s. This level of thrust, 100 Newtons, is helpful only for small scale spacecraft in deep space engaged in very long-range missions over long time frames since the acceleration is very low.

Rocket Engine Energy and Temperature

In his 1951 book Interplanetary Flight: An Introduction to Astonautics, Arthur C. Clarke addresses the limitations of increasing rocket exhaust velocities in order to increase the Newtons of thrust of the rocket. He uses the German V-2 rocket used in World War II to illustrate his point. The V-2, he says, had an exhaust velocity of 2,250 m/s. Using the standard formula for kinetic energy in joules, KE = ½ mv^2, KE = ½ 104.69 x 2,250^2 = 265,000,000 J, where 104.69 is the kilograms of the material exhausted at 2,250 meters per second squared. This equals 265,000,000 W of power or 265,000 KW. Clarke didn't give the mass exhausted, so I divided 265,000,000 by ½ x 2,250^2 Km/s to get 104.69 Kg. This mass was being expelled every second. We can calculate the thrust of the V2 rocket as 104.69 kg/s x 2,250 m/s = 235,553 Newtons. Online information says that the rocket operated for 60-70 seconds. This would mean that it

burned 70 seconds x 104.69 kg or 7,328 kg of fuel. Since Clarke says that the V-2 still had a mass of about 4,000 kg when the fuel was nearly exhausted, the V-2 at lift off must have had a mass of about 11,000 kg.

Clarke then imagines increasing the exhaust velocity of the rocket by 1000 times to 2,250,000 m/s. We can then take ½ x 104.69 x 2,250,000^2 and get 265,000,000,000 W or 265,000,000 KW. The KW generated is 1,000 times greater. This much energy, Clarke says, would inevitably leak into the rocket and vaporize it.

But 2,250,000 m/s or 2,250 km/s is very far from the speed of light which is 300,000 km/s, very far from being a relativistic speed. If the exhaust velocity was increased again by 100 times, we would have 225,000 km/s or 0.75 light speed, generally represented as 0.75c. In this case the relativistic formula for kinetic energy would apply: KE = mc x [1/square root of 1-(v/c)^2 – 1]. For convenience we can define c = 1. Then the non-relativistic formula, KE = ½ mv^2, is KE = ½ x 0.75^2 = 0.28 and the relativistic formula gives KE = 0.51. The relativistic result is 82% greater than the non-relativistic result at 0.75c and the difference grows greater at even higher exhaust velocities. This is one more reason why relativistic exhaust velocities are impractical and would be disastrous for any spaceship we might build.

Another, more familiar, way of looking at this issue is from the perspective of the temperature of the exhaust gases. Isaac Asimov, in his 1969 book View From A Height, presented a simple and elegant formula for determining the temperature in degrees Kelvin of a gas moving at a given velocity. His formula is degrees Kelvin = 40 x the atomic mass of the element or molecule making up the gas x the velocity of the gas squared, or T = 40 mv^2. The atomic mass is in Kg, the velocity is in Km/s, and the resulting temperature is in degrees Kelvin.

In his book Asimov discusses whether there is any maximum temperature analogous to the maximum velocity of light. He uses his formula to calculate the temperature when the velocity

reaches the speed of light. At the temperatures produced at light speed only protons and neutrons could exist, so he uses the atomic mass of the proton or 1. Asimov then goes on to point out that as material objects approach light speed, according to Special Relativity, the mass of the object increases, ultimately without limit. Because of this increase in mass without limit, temperature has no upper limit either.

This means that a rocket exhaust consisting of protons speeding at near light speeds would vaporize a spacecraft and everything and everyone in it.

Using Asimov's formula and Clarke's V-2 example, we can calculate the exhaust temperature in degrees Kelvin. I have estimated the atomic mass of the V-2 alcohol-oxygen propellant mix as 2.6 for the eight light hydrogen atoms contained in the mix of C2H6O, H2O, and O2. This generates a temperature of 40 x 2.6 x 2.25^2 or 527 degrees Kelvin (254 degrees Celsius or 488 degrees Fahrenheit). Now for Clarke's imagined scenario of increasing the exhaust velocity 1,000 times to 2,250 km/s. This generates a temperature of 40 x 2.6 x 2250^2 or 526,500,000 degrees Kelvin which would leak into the spacecraft and incinerate it.

The exhaust velocity has an overwhelming effect on the temperature because it is squared in the formula. And since any metal will melt before it reaches 4,000 degrees Kelvin, any leakage of heat into the spacecraft would be disastrous.

Clarke goes on to speculate about using hydrogen molecules (H2, atomic mass 2) or helium (He, atomic mass 4) as propellants in an atomic-thermal rocket engine where the atomic pile heats the hydrogen or helium and exhausts it out the back of the rocket. Clarke says that 10 km/s to 15 km/s exhaust velocities should be safely attainable. If we run the numbers, we get T = 40 x 2 (H2) x 10^2 = 8,000 degrees Kelvin and T = 40 x 2 (H) x 15^2 = 18,000 degrees Kelvin. The helium temperatures would be twice as high. These temperatures, if heat leakage occurred, would incinerate any spacecraft. Clarke also discusses using water as a propellant

in a nuclear-thermal rocket engine. At high temperature, H2O separates into 2H2 and O2 and thus hydrogen molecules (H2) become the propellant with an atomic number of 2, resulting in 18,000 degrees Kelvin and the incineration of the engine, the ship and its occupants.

Asimov didn't present a derivation but here is how it may be derived.

It has been established that kinetic energy KE = ½ mv^2 or one half the mass x velocity squared. It has also been established by the molecular theory of gases that KE = 3/2 k T where k is the Boltzmann Constant 1.38 x 10^-23 Joules per degree Kelvin and T is the average temperature of a mole of the atoms or molecules of the gas. Since ½ mv^2 = 3/2 k T, we can proceed to rearrange the equation to identify the formula for any one of the terms involved. Thus v = (3kT/m^1/2 and T = (mv^2)/3k. So, T = 1/3k (mv^2). This formula deals with moles of atoms or molecules and Avogadro's Number states that a mole of any type of atoms or molecules contains 6.02 x 10^23 atoms or molecules. In 1/3k (mv^2) the 1 stands for one atom or molecule. Therefore, 1 atom = 1/6.02 x 10^23 atoms per mole equals 1.66 x 10^-24. And 3k = 3 x 1.38 x 10^-23 = 4.14 x 10^-23. Then, 1 atom/3k = (1.66 x 10^-24)/(4.14 x 10^-23) = 0.0400966. Now back to our equation 1/3k (mv^2). Substituting the value of 1/3k we get 0.0400966 (mv^2) with v in units of meters per second. We can convert the units of velocity to Km/s and multiple 0.0400966 by 1,000 to get the formula 40.0966 (mv^2). And we may now shorten the terms of the number 40.0966 to the approximation of just 40 and get the simple and elegant Asimov formula T = 40 mv^2 with T in units of degrees Kelvin, m in units of atomic mass of the type of atoms or molecules in the gas, and v in units of km/s.

In a discussion of rocket fuels, Clarke suggests methane as an attractive fuel. Both SpaceX and Blue Origin, two major developers of interplanetary spacecraft, have turned to the use of methane as their rocket fuel. Clarke points out that methane, CH4, has an atomic weight of 16.04, which is 12 + 4 x 1.01 =

16.04/one mole, but that the molecules dissociate immediately when oxidized into C (solid) and 2H2 with a lower atomic weight of 5.34, which is 16.04/3 moles, allowing for higher exhaust velocities as the expansion pressure of the burning gases forces the lighter molecules to higher velocity.

When CH4 decomposes into C (solid) and 2H2, it decomposes from one mole to three moles and the molecular weight becomes 16.04/3 = 5.34 per mole. This fact and the expectation of being able to produce methane in outer space from the materials of asteroids, moons and planets has led both SpaceX and Blue Origin to develop rocket engines designed to use methane as propellant and oxygen as oxidizer. Methane requires an input of energy, an electrical or chemical “spark”, to ignite its combustion with oxygen. Then C (solid) and 2H2 combine with 2O2 to decompose into CO2 and 2H2O.

When it comes to chemical rocket fuels, a lower molecular weight is desirable because it allows for higher exhaust velocity and more rapid mass ejection, thus increasing thrust. That is why the lightest element, hydrogen or H2, has been a common rocket fuel.

When molecular weight is discussed, we are really talking about molecular mass. Weight is mass times a gravitational field value and differs greatly on earth, on the moon (1/6 earth gravity), and drifting in space at zero gravity. The atomic mass remains the same in any gravitational field or outside any perceptible gravity.

SpaceX rockets exclusively use methane as their propellant along with liquid oxygen (LOX) as an oxidizer. The exhaust velocity of the Falcon series Merlin engines is 2,764 meters per second and for the Starship Raptor engines it is 3,234 m/s. The exhaust velocity of the Blue Origin BE-4 engines of their New Glenn rocket, also using methane and LOX, is 3,038 m/s. These numbers translate into temperatures of 40 x 5.34 x exhaust velocity squared. For the Merlin engines the temperature is 1,632 degrees Kelvin, for the Raptor engines 2,234 degrees Kelvin and for the BE-4 engines 1,971 degrees Kelvin. All of these are well

below 4,000 degrees Kelvin, where any material object incinerates. We can calculate at what exhaust velocity any of these rockets would reach the 4,000 degree Kelvin threshold when all material objects incinerate, as v = [4,000/(40 x 5.34)]^1/2 = 4.327 km/s or 4,327 m/s.

We can look at the proposed photon rocket in this context of exhaust velocity and temperature as well.

The photon, as is well known, has no mass. At first glance this would seem to be an advantage, an escape hatch from the peril of vaporizing temperatures at high exhaust velocities since T = 40 x 0 x light speed = 0.

But would a photon rocket engine really generate zero energy and zero temperature? No, not really. Einstein pointed out in 1905 that E = mc^2 where E stands for energy in Joules, m stands for mass in kg and c is light speed in meters per second. Energy and mass are interchangeable. Mass is an extremely compact form of energy, m = E/c^2.

So, what is the energy of a photon? It depends on the frequency, the number of cycles per second, of the particular photon. The Hertz (Hz) is one cycle per second. A one Hz photon has energy equal to 6.626 x 10^-34 Joules. For our purposes let’s use light photons which have an average frequency of 10^16 Hz or cycles per second. The mass of a light photon, then, is equal to 10^16 x 6.626 x 10^-34 Joules/(300,000 Km)^2 = 7.4 x 10^-29 kg. Temperature = 40 x 7.4 x 10^-29 x 300,000^2 = 2.7 x 10^-16 degrees Kelvin. Very cool indeed.

However, having grown satisfied with the temperature of the exhaust of photons, we need to ask what thrust this photon rocket will provide to move the spaceship, which relies on action and reaction to move in space. Spacecraft must generate momentum in the direction opposite the direction they wish to travel. Momentum is defined as mass in kg x velocity in m/s. In this case, we are throwing photons out the back of the spacecraft, each with a mass of 7.4 x 10^-29 kg. The mass thrown per

second times the exhaust velocity equals the force driving the spaceship. One photon per second times light speed = 7.4 x 10^-29 x 300,000,000 meters per second = 2.22 x 10^-20 Newtons of force. You need 4.545 x 10^19 photons per second to achieve one Newton of force. A 60-Watt light bulb emits less than 2000 photons per second. The most powerful laser built to date generates 10^16 directed photons per second. This would produce 10^16/4.545 x 10^19 = 2.2 x 10^-4 Newtons or much less than one Newton of force. One Newton of force acting on a 100,000 kg spaceship would produce an acceleration of 1/100,000 or 10^-5 meters per second squared. At this acceleration rate, it would take 100,000 seconds, more than one day, to move the ship one meter and 1,000 days or nearly three years to move the ship one kilometer. A photon rocket engine, even if feasible, holds little promise to power spacecraft.

A Final Note on Energy and Thrust

Energy and thrust are two different things.

In space there is no momentum and no change of motion without the ejection of mass. You can generate a huge amount of energy on board a spacecraft by employing a nuclear reactor or theoretically using matter-antimatter reactions. But this doesn't generate any thrust. The only point of using a nuclear reactor or matter-antimatter reactions to generate energy with a small amount of mass as fuel is to use the heat generated to heat some other mass to create pressure to eject that mass from the spacecraft. Let's say you heat water and eject water vapor mass. This means you must carry a large enough mass of water to create the momentum you desire.

E = mc^2 can generate a lot of heat, enough to melt any material object including a spacecraft, but it doesn't produce any directed thrust. When an atom bomb goes off it explodes in every direction. It will incinerate any spacecraft; it won't send a spacecraft in any desired direction.

The reality of energy and thrust makes acceleration and deceleration in space on a grand scale virtually impossible for a spacecraft.

Section III, Biology

Dangers to Humans Living Off the Earth

Humans have lived for a little over a year continuously on-board the space station circling the earth at about 250 miles distance, within the Very Low Earth Orbit (VLEO) zone of 62 to 280 miles above earth. Low Earth Orbit (LEO) extends from 280 to 1,200 miles above earth. Many serious physiological problems have been documented in those living in a gravity-free environment on the International Space Station. And humans aboard the space station are still within the protective shield of earth as far as radiation is concerned. Even so, they receive about 62 times the radiation on earth at sea level. The radiation level on the surface of the moon or Mars is 83 times earth level. In the vacuum of space within our solar system, radiation is 250 times earth level. The space station does not provide any data about the effects of living in the radiation-saturated arena of outer space within our solar system, let alone about the radiation conditions in space far outside our solar system. Our sun's heliosphere, a huge irregular bubble of plasma, protects our solar system from much interstellar radiation. Voyagers I and II are the only spacecraft which have reached interstellar space beyond our heliosphere. They recorded a 100-fold increase in high-energy electron radiation after they left the protective envelope of our sun's heliosphere. If solar system radiation is 250 times greater than radiation encountered on earth, then radiation in interstellar space may be 100 times greater or 25,000 times greater than radiation encountered on earth. This level of radiation would be deadly to human beings and to any earth life forms and may constitute a barrier to human travel beyond our solar system.

Following is a summary of many of the issues facing humans living in near-earth orbit on the International Space Station, based

on “Effect of space flight on the human body” on Wikipedia, downloaded in December 2023.

The dependence on a life support system for air, water and food. Dealing with bodily wastes. Shielding from radiation and micro-meteorites.

Up to 80% of astronauts suffer a common “space sickness” syndrome lasting for a few days while adjusting to zero gravity with nausea, vomiting, dizziness, fatigue, headaches, vertigo and cold sweating.

The effects of microgravity such as loss of the sense of one’s own body movements (proprioception), changes in body fluid distribution, deterioration of muscles and the skeleton (loss of bone mass), and a weakening of the immune system.

Other effects, such as serious changes in the position and structure of the brain, damage to the gastrointestinal tissues, premature aging, physical changes to the eyes and eyesight, lessened sense of taste, and the pervasive distribution of unpleasant odors in the air.

Among the psychological concerns are anxiety, insomnia, depression and interpersonal conflict. These problems could be enormous for those living in spacecraft for long periods, living on other planets or in large artificial biospheres.

On the level of microbes, latent viruses in the body may be activated with harmful effects. Microbes have been found to thrive in space. Some microbes even survive in the vacuum of space. With or without lowered immune systems, humans could be subject to illness from rapidly evolving microbes.

These are the short-term effects, over days or many months, observed in humans living in the relative safety of earth orbit and still enjoying earth’s magnetosphere protection from dangerous space radiation. The long-term physiological effects of living in the vacuum of space are unknown. One researcher suggests that

on a months-long trip to Mars all the astronauts would develop cancer from exposure to high radiation.

Psychological and social effects are also huge concerns and don't bode well for human survival in such changed circumstances.

Sailing ships always had a commander with near-absolute powers over everyone else on board. This model of political/social organization seems to be carrying over into the space exploration arena. Imagine this model operating on a large spaceship, a huge biosphere in space or in a colony established on another planet. The potential for explosive social chaos would be enormous. If humans can't cooperate on earth, there is little reason to expect cooperation in space.

The effects of procreation in space and of children being conceived and growing up in space with zero gravity or on earth's moon with 1/6 earth gravity or on an alien planet like Mars, with 1/3 earth gravity, are also unknown.

And the aftereffects of living without gravity are very great. It can take days or even weeks for astronauts returning from months on the International Space Station to adjust to gravity on earth. One concern about traveling to Mars is that weakened crew members would be unable to proceed with their tasks on the surface of the planet Mars even though its gravity is but 1/3 that of earth.

Limitations Imposed by the Length of A Human Life

Discounting the serious health and survival problems of living in space, the length of a human life places serious limits upon how far humans can travel in space during a single lifetime. Assuming that astronauts can be educated, trained and ready to engage in space travel by age 25, conceivably a crew might travel outward for fifteen years, explore a destination for a year, and make a return trip of another fifteen years. This would make the crew 56 years old upon their return to earth.

Using the generous speed of NASA's proposed 2035 Mars mission of an average speed through space of 46,000 miles per hour, this

would allow the crew to travel 46,000 mph x 24 hours/day x 365 days/year x 31 years or 1.25 x 10^10 miles. Thus, the crew might reach Neptune, the most distant outer planet in our solar system at 2.7 x 10^9 miles, and return in their lifetime, at least theoretically. Our nearest star, Proxima Centauri, at 2.46 x 10^13 miles distance, would be far out of reach, however, since such a trip would require about 2,000 years one way.

This assumes that humans could biologically survive long-term space living at all.

Can We Create Artificial Gravity for Astronauts?

Gravity is an attractive force between any objects having mass. A large material object like earth holds smaller objects like humans in a powerful grip. All life on earth evolved in the grip of earth's gravity. When life forms are placed in a weightless environment, every aspect of their complex functions is affected. Rapidly reproducing microbes evolve differently in a weightless environment. Long-term exposure to zero gravity has devastating effects on human health and physical abilities. For these reasons, long-term stays in space such as a trip to and from Mars may not be feasible without an artificial gravity environment.

The images from television and movies of Captain Kirk and his crew on the command bridge and throughout the Starship Enterprise spacecraft walking around as if they were on earth is a science fiction illusion. Without gravity to hold them in place, they would be floating about randomly.

With the renewed interest in human exploration of our solar system, particularly of our moon and Mars, space institutions and companies are beginning to come to grips with what real long-range space travel and living off the earth requires. It is not just a rocket and fuel. Energy is needed to escape the gravitational grip of earth. But once outside earth's gravity, artificial gravity must be reimposed for the health and happiness of a human crew. Zero gravity can be tolerated for a time, but long-range space travel such as a trip to Mars and back requiring up to two and a half years may be impossible without some type of artificial gravity.

The current plans of NASA and other agencies for Mars travel do not include artificial gravity because of the difficulties and

expense involved. But there seems to be a growing awareness that this is an urgent issue.

There are two known ways of creating an artificial gravity environment. One is by means of linear acceleration and the other is by means of a rotating wheel.

Artificial Gravity By Means of Linear Acceleration

In a rocket ship accelerating at 9.8 m/s^2 we would feel the same force as gravity on earth pushing us in the direction opposite to the rocket's direction of travel. We could accelerate toward our objective, say Mars, for half the distance, then turn the ship around and decelerate for the last half of the distance. By turning around for deceleration, the direction of gravity inside the ship would stay the same. The ship might have several stories of usable habitat and workspace with steps or an elevator moving people from one level to another.

Up to this point, artificial gravity by means of linear acceleration looks like it might work. However, linear acceleration requires a significant continuous application of force. The only rockets capable of the force required make use of chemical fuels.

This brings us back to the Rocket Equation

$$M_i \,/\, M_f = e^{(\frac{delta\,V}{Ve})}$$

where $M_i$is the mass of the rocket and fuel and payload

Mf is the mass of the payload

e is the transcendental number 2.718…

delta V is the change in velocity that we want to achieve

Ve is the exhaust velocity of the rocket.

We need the delta V or velocity goal before we can calculate this equation, however, so we need to take a diversion first to accomplish this.

The equations involving linear acceleration are:

1: g = a, i.e., gravity = acceleration.

2: v = at, i.e., velocity = acceleration x time

E.g., v = 9.8 (m/s^2) x 6 (seconds) = 58.8 m/s.

t = v/a (e.g., t = 58.8 (m/s)/9.8 (m/s^2) = 6 seconds

a = v/t (e.g., a = 58.8 (m/s)/6 (s) = 9.8 m/s^2

3: d = o.5at^2, i.e., distance covered = 0.5 x acceleration x time^2.

E.g., d = 0.5 x 9.8 (m/s^2) x 6^2 (s) = 176.4 meters.

t = (d/0.5a)^1/2 = [176.4 (m)/(.05 x 9.8 (m/s^2))]^1/2 = 6 seconds

a = d/0.5t^2 = 176.4 (m)/0.5 x 6^2(s) = 9.8 m/s^2

Let's use the closest distance ever measured between earth and Mars (August 2003) of 34.8 million miles or 56 million kilometers. The orbits of earth and Mars approach closest to each other about every 26 months. Half this distance is 28 million kilometers. Using the formula t = d/0.5a, we have t = [28 x 10^9 meters/(0.5 x 9.8 m/s^2)]^1/2 = 75,593 seconds. We will reach a velocity of v = at, or v = 9.8 x 75,593 = 740,811 m/s or 741 km/s. This result times 0.621 = 460 miles per second or 1,656,158 mph.

Now we will plug the velocity goal, 740,811 m/s, and the estimated exhaust velocity, 4,000 m/s, into the Rocket Equation.

Mi/Mf = e^(740,811/4000) = e^185.5 = 2.7 x 10^80, a huge number.

Then we would need to turn the ship around and fire the rockets again for 75,593 seconds to bring the ship to a stop at Mars.

The entire trip to Mars and then back to earth, stopping at each destination, requires fuel of (2.7 x 10^80)^4 x the ship mass without fuel.

We can see that the mass of the ship without any fuel is irrelevant here because of the gigantic magnitude of the fuel requirement.

And we can see that using linear acceleration to generate artificial gravity is completely impractical.

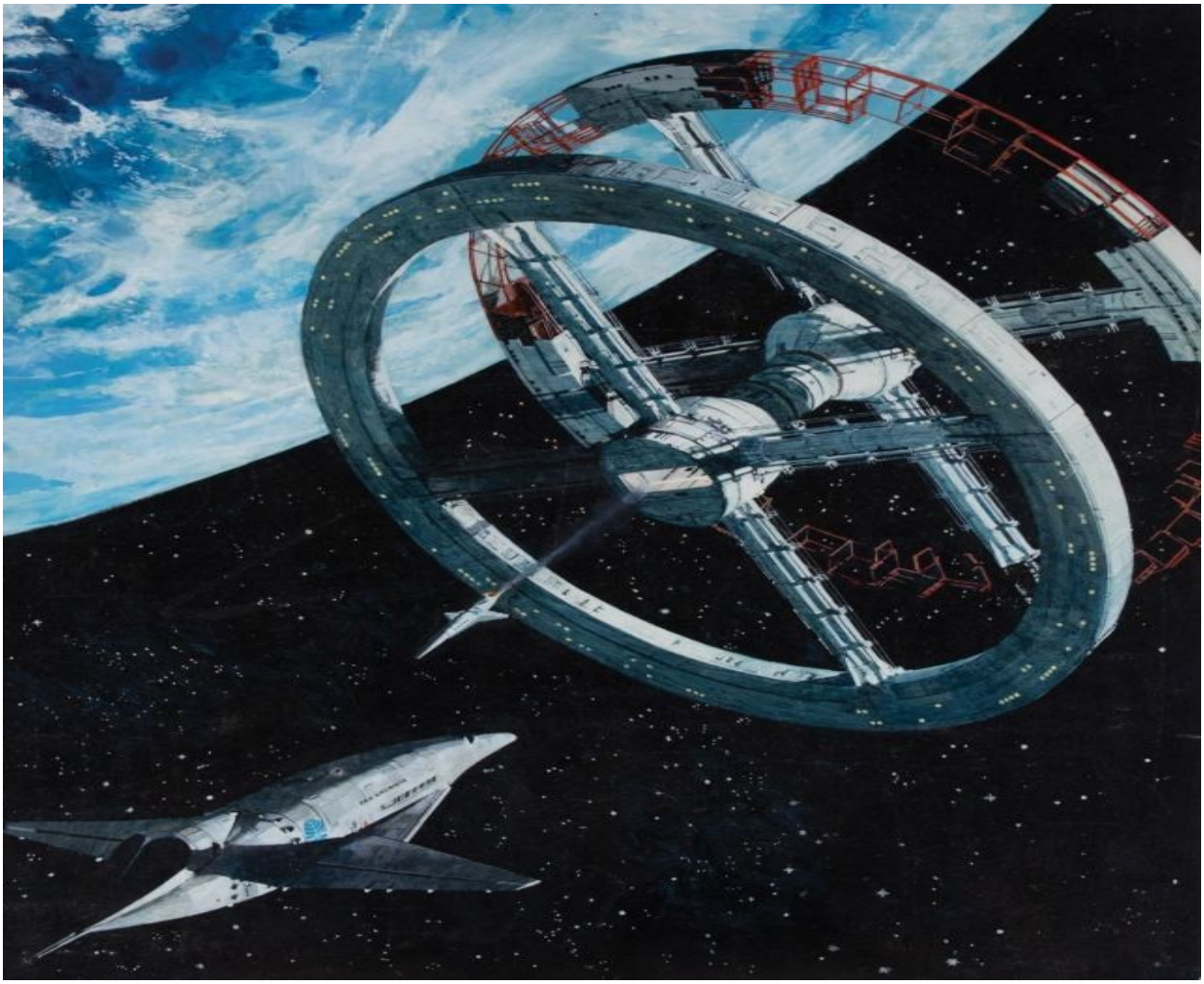
What about the other option for generating artificial gravity, the rotating wheel?

Artificial Gravity By Means of A Rotating Wheel

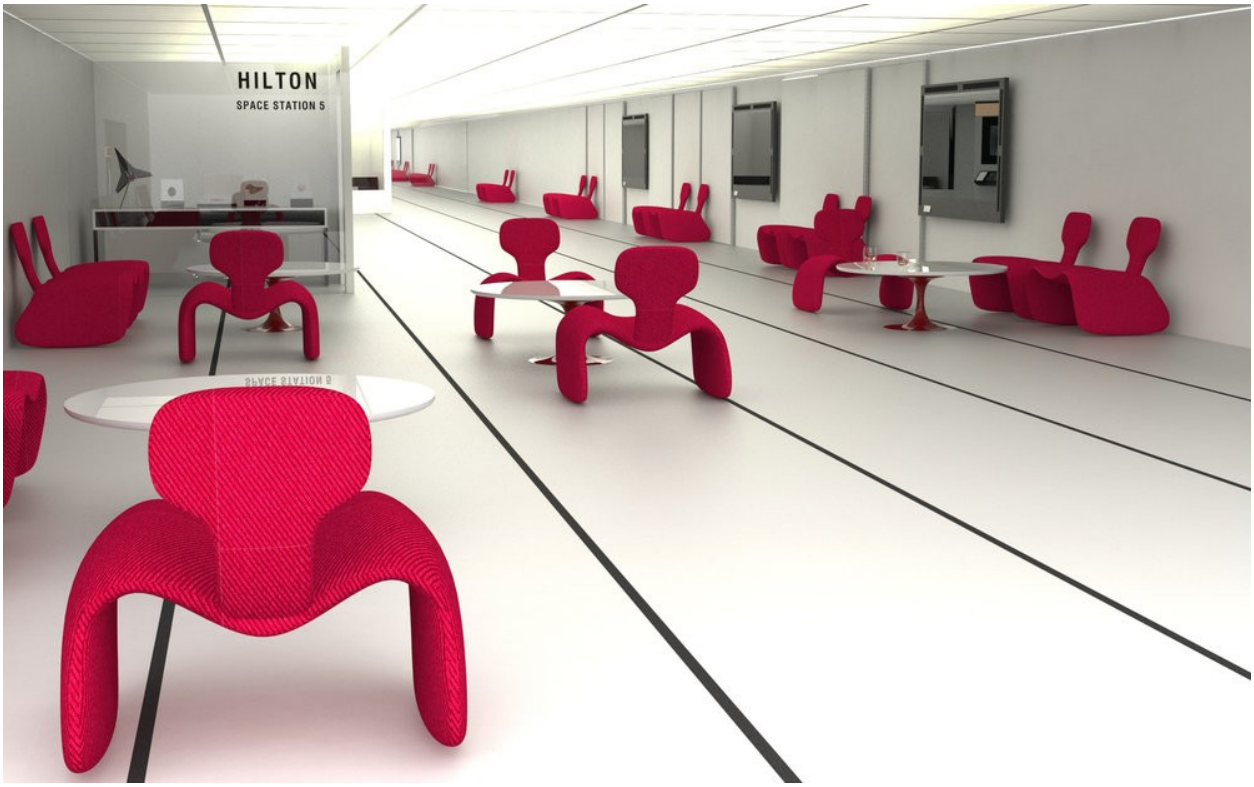
When a space wheel rotates it creates the feeling of gravity at the outer rim of the wheel. The maximum magnitude of gravity is felt at the outer rim, while the magnitude declines as you approach the center of the space wheel where the magnitude falls to zero. Because the space wheel has nowhere near the radius of the earth, the magnitude of gravity falls off rapidly away from the surface of the outer rim. If the radius of the space wheel is too small, the gravity difference between the feet and the head can be significant and lead to physical problems and mental confusion. And the Coriolis Effect, where objects fall in the opposite direction of the spin, can cause a disruption to the inner ear and disorientation if its magnitude is too large.

Many of the potential problems of the rotating wheel can be solved by increasing the radius of the wheel. However, there is a cost to this in materials and build time.

Let’s begin with the example of a space station orbiting earth before tackling an artificial gravity wheel connected to a spacecraft.



I will use Space Station V from the book and movie 2001 to illustrate artificial gravity on a space wheel. I have included two images of Space Station V, one from outside looking at the whole station and one from inside showing the slowly rising pathway around the rim of the rotating wheel. It is at the outer rim of the rotating wheel that the maximum force of artificial gravity is felt.



As for the gravity, radius, and the rotation rate of the space station, let's look at how this is determined.

Space wheel calculations involve the parameters of the gravity effect, the radius of the wheel, and the rotation rate of the spinning wheel. A basic equation needed for determining space wheel parameters is w = $\sqrt{g/r}$ or w = (g/r)^1/2 where w represents the radians of rotation per second, g is the gravity effect at the outer surface of the wheel in meters per second, and r is the radius of the wheel in meters. One radian equals 57.3 radians. A full rotation is equal to 2 pi radians or 360 degrees.

I will designate the space wheel parameters as (g, r, c) where g is gravity (m/s^2), r is radius (m) and c is the seconds to achieve a full rotation and is calculated as 360 degrees divided by 57.3 x w. RPM (rotations per minute) = 60 seconds/c; if c = 60 seconds, the RPM is 1.

The equations of (g,r,c) are then (g = rw^2, r = g/w^2, c = 360/57.3w). We can see that w = (g/r)^1/2 = (360/c)/57.3. If we know g and r, we can use the first equation to find the value of w; if we know c, we can use the second formula to find the value of w. Once we know the value of w, we can find the value of the missing variable of (g,r,c), such as (?,r,c), (g,?,c) or (g,r,?). Keep in mind that g is the gravity value in m/s^2 at the outer rim of the wheel, r is the radius of the wheel in meters, and c is the seconds required for a full 360 degree rotation of the wheel. It may be helpful to list these equations as follows:

(gravity [m/s^2], radius [m], seconds for a full rotation [s]) = (g,r,c)

Revolutions Per Minute (RPM) = 60 seconds/c

w = (g/r)^1/2 = (360/c)/57.3

g = rw^2

r = g/w^2

The book 2001 describes Space Station V as having a maximum gravity at its outer rim of 1.62 m/s^2 (equivalent to lunar gravity), a radius of 150 meters (equal to 492 feet), and a full rotation every 61 seconds. I will designate this as (1.62, 150, 61) 1 RPM.

The movie 2001, on the other hand, purported to have a maximum gravity of 9.8 m/s^2 (equivalent to earth gravity), a radius of 150 meters, and a rotation rate of 60 seconds, (9.8, 150, 60) 1 RPM.

Arthur C. Clarke was an engineer and had worked out his numbers using the standard formulas for a rotating wheel in space. Stanley Kubick was a movie maker and used artistic license. He made a good movie, but generating 9.8 m/s^2 gravity with a 60 second revolution rate (1 RPM) requires that the radius of the wheel be 894 meters, not 150. Or, alternatively, generating 9.8 m/s^2 gravity with a wheel radius of 150 meters would require a 25 second revolution rate (equal to 60/25 = 2.4

RPM). A revolution rate greater than 2 RPM is considered hazardous to the human senses and health.

The calculations for (9.8, r, 60) are as follows:

w = (360/60)/57.3 = 0.1047 and w^2 = 0.01096; r = 9.8/0.01096 = 894 meters.

For (9.8, 150, c) the calculations are as follows:

w = (9.8/150)^1/2 = 0.2556 and c = 360/(57.3 x 0.2556) = 25 seconds or 2.4 RPM.

Now let's look at a space station with parameters designed for human safety and comfort, 9.8 m/s^2 gravity at the outer rim with a rotation rate of 120 seconds and let's determine the radius required for (9.8, r, 120).

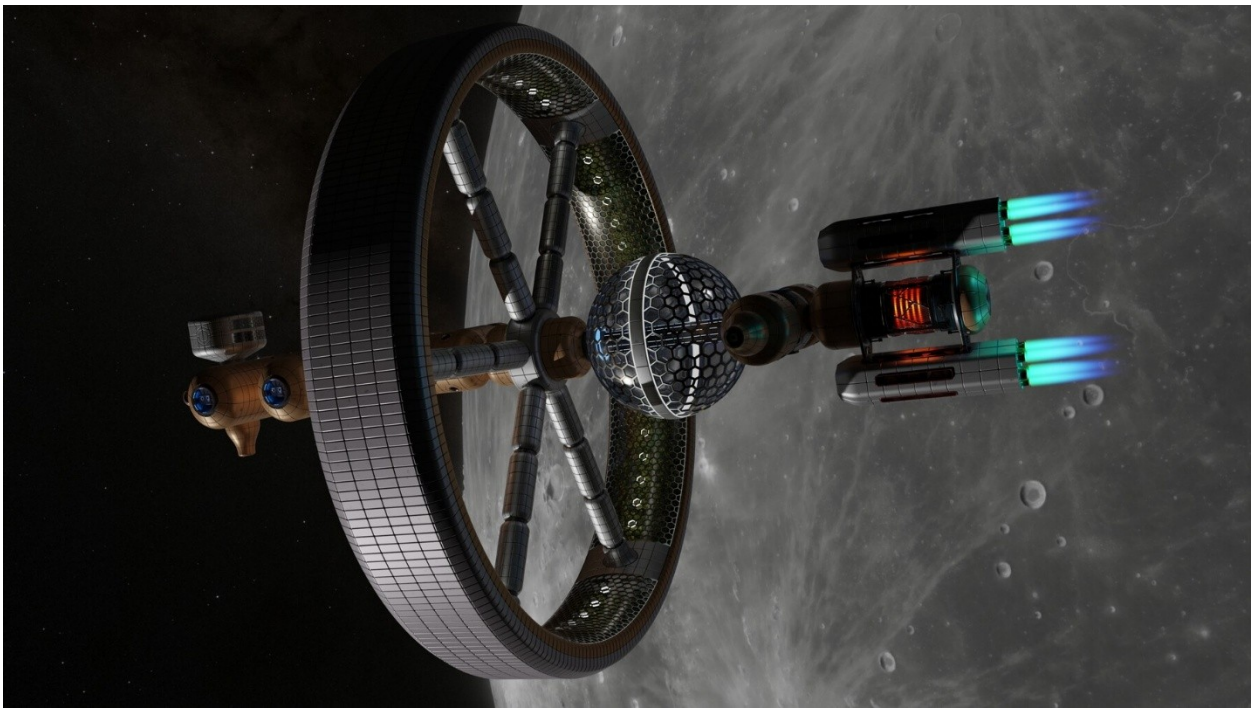
w = (360/120)/57.3 = 0.05236 and w^2 = 0.00274; r = 9.8/0.00274 = 3575 meters.

Our space wheel parameters are (9.8, 3575, 120) and RPM = 60/120 = 0.5 with a full rotation every two minutes, a safe and comfortable rotation rate for humans.

Of course, this space station is enormous. It has a radius about 24 times greater than the space wheel in the movie 2001. Expressed in feet at 3.281 feet per meter, our space wheel radius is 11,730 feet or about 2.2 miles using 5280 feet per mile. The diameter is 4.4 miles and the circumference (2 pi r) is about 14 miles.

Such a spaceship might look like the following image. However, for starting out and then stopping at a destination, it should have rocket engines at both ends of the bar running through the center of the rotating wheel. Otherwise, the ship would have to first turn around 180 degrees before firing the engines in order to slow down and stop at a destination. Unlike the acceleration model of simulating gravity, with the rotating wheel we don't have to worry about changing the ship's direction in order to keep the gravitational forces constant. The simulated gravity at the rim of

the wheel remains constant no matter which direction the ship is traveling.



However, the maximum gravity of a space wheel is felt only at the outer rim of the wheel and falls off as you approach the center of the wheel where gravity goes to zero.

For a rotating sphere, such as a biosphere, full maximum gravity would be felt only along the equator of rotation. Gravity would fall away on the internal surface of the sphere as you move away from the equator toward the poles of the sphere where gravity would be zero. When you move into the volume of the sphere toward the center, gravity also falls away until it reaches zero at the center.

The Coriolis Effect

Now let’s look at the Coriolis Effect aboard our space wheel with parameters (9.8, 3575, 120).

On earth, when we drop an object, let’s say a pen, it falls straight to earth and we can reach straight down to pick it up. But, aboard a spinning space station when we drop a pen the station moves a bit before the pen reaches the floor. We will have to

bend over and reach out a bit to pick the pen up. We want to know, for our space station, just how far the pen, or any object, will fall further along the station floor in the direction counter to the spin direction. If the magnitude is too great, the effect is disorienting and may be dangerous.

The magnitude of the Coriolis Effect depends on the radius of the space station and the distance of the drop. We will assume that the pen is dropped from a hand which is held about one meter, 3.281 feet, above the surface. The radius of the station is 3575 meters. Subtracting one meter from this we have 3574 meters. With this setup, we will designate R = 3575 meters and r = 3574 meters for this formula.

The distance in meters that an object will fall differently from a straight fall to the floor is

$$d=R(\sqrt{\frac{R^2}{r^2}-1}-\cos^{-1}\frac{r}{R}/57.3)$$

The calculations for the space wheel with parameters (9.8,3575,120) are:

d = 3575{[(3575^2/3574^2)-1]^1/2 – cos^-1(3574/3575)[/57.3]}

= 3575{[(12780625/12773476 -1)^1/2 – cos^-1(.99972)[/57.3]}

= 3575{(.00056^1/2) – 1.3559/57.3}

= 3575{.023664 - .023663}

= 3575{.000001} = .0036 meters

.0036 (3.281 feet) = .0117 feet

.0117 (12 inches) = 0.14 inches

About 1/10 of an inch. We would hardly notice this difference if we dropped a pen or a book or a tool from our hand to the floor.

In contrast, the Coriolis effect of the 2001 movie version of a space wheel with a corrected rotation rate (9.8, 150, 25) would be 3.07 inches. Anything around 3 inches or less is considered acceptable. But this value is 22 times greater than on my recommended wheel with (9.8, 3575, 120) parameters.

Curvature at the Outer Rim

Now let's look at the curvature of the rim of our (9.8, 3575, 120) space station.

For this we need the rise and run numbers, just as we use rise and run numbers when constructing a stairway. From the rise to run ratio, we can calculate the degrees of curvature of the space station or slope.

The rise of any circle or circular object is (1/radius) x one radian.

So, rise = (1/3575) x 57.3 = 0.016. The run is 1/rise = 1/0.016 = 62. The run is also equal to the circumference of the space station divided by 360 degrees. In this case, 2 pi r = 22,462 and 22,462/360 = 62. Dividing the rise and run numbers by the rise, 0.016, gives 1 : 3900 we have the rise to run ratio.

This means that for every 3600 units we walk along the rim of the space station, we rise 1 unit. Every 3900 feet we rise 1 foot.

What is the angle in degrees that this represents?

The slope in degrees of the rim of the space station is equal to tan^-1 of (1/3900) = .015 degrees and would hardly be noticeable.

A wheelchair ramp is recommended to have a ratio of 1 : 12 or more, which equals tan^-1 (1/12) = 4.76 degrees maximum. Our space station slope is far less than this and would seem almost level to humans walking around the wheel.

In contrast, the 2001 movie space wheel (9.8, 150, 25) has a rise of 1/150 x 57.3 = 0.382 and a run of 1/rise = 1/0.382 = 2.62. The normalized rise to run ratio is 1 : 6.85 meaning that for every 6.85 feet we travel, we rise 1 foot. The slope is tan^-1 (1/6.85) = 8.3

degrees, almost twice what would be recommended as the maximum for a wheelchair ramp.

Size and Expense of a Rotating Space Wheel

The space station I recommend for safety and comfort, (9.8, 3575, 120) is very large, much larger than Space Station V in the movie 2001.

This enormous size may be fine for a permanent space station orbiting earth, but what about building a spacecraft with artificial gravity, one that may travel for 2 ½ years to Mars, orbit Mars for some time and then return to earth?

It is no wonder that NASA is searching for alternatives that would provide a little bit of gravity experience during the long Mars mission without the expense and difficulty of providing a complete artificial earth gravity environment.

The movie 2001 also had a long-range spaceship called Discovery One with an internal artificial gravity wheel. According to Arthur C. Clarke, this wheel had a radius of 11.6 meters (38 feet) and rotated at 3 RPM (60/3 = 20 seconds per revolution). Using the formulas we have already reviewed, the gravity generated by this wheel would be 1.14 m/s^2, less than the 1.62 m/s^2 on the surface of our moon and about 1/10 of earth gravity. In terms I used previously, these specifications are (1.14, 11.6, 20) and 3 RPM.

To generate earth level gravity, the revolution rate would have to be c = 360/[(9.8/11.6)^1/2 x 57.3] = 6.84 seconds per revolution or 60/6.84 = 8.8 RPM, which would be completely disorienting and dangerous to human health.

A NASA-sponsored engineering concept paper in 2005 described a ship which they called Discovery Two, which had three spokes with a habitat/work station at the end of each spoke. The spokes and habitats were designed to spin around and produce a low level of gravity. The specifications were (1.96, 17, 18). The

gravity generated is a bit greater than on the lunar surface and the rotation rate is 60/18 = 3.3 RPM, a dangerous rotation rate.

Neither Discovery One nor Discovery Two offers much to a crew on a long-range mission in space with their very low gravity and high RPM.

Artists have provided some conceptual images of possible combinations of a rotating artificial gravity habitat with a spacecraft designed for long-range space travel.

One image shows a ship with rocket engines on one end of the spacecraft, a rotating wheel attached in the center of the ship, and two SpaceX-like Starships attached at docking stations at the forward end of the ship, ready to detach and land on Mars, for example, after the spacecraft goes into orbit around the planet. The image shows a habitat equal in size to Space Station V of the movie 2001, but with a single rotating habitat.

Giving space travelers the benefits of full earth gravity seems critical for safe and healthy space living. The best solution in terms of a space wheel might be something like my

recommended wheel with parameters (9.8,3575,120) and 0.5 RPM: earth gravity, slow rotation and a large radius.

But the enormity of such a space wheel, perhaps with rockets located at the center of its hub to enable travel through space, makes this proposal extremely unlikely.

An artificial gravity wheel with parameters acceptable for humans and other earth life forms seems as impractical as the linear acceleration solution.

The Biology of Life

Even if all the physiological limitations described above could be somehow overcome or lived with, considerations of evolutionary biology appear to impose impenetrable barriers to humans living in space, in spacecraft, on other planets or in artificial biospheres either orbiting earth or traveling through space.

We are probably confined physically to earth, where we evolved along with all the other organisms that make us alive and keep us alive. The dangers to humans of long-term space travel in spacecraft or artificial biospheres are enormous. There are the dangers of weightlessness and of ionizing radiation that I have mentioned.

The other great danger is evolution itself. We humans evolved through chemical evolution after billions of years of microbial life on earth within the grasp of a specific gravitational force. A different gravitational field scrambles all the evolutionary parameters of our physiology and of the many microbes inside and outside our bodies. Also, we evolved to survive the onslaughts of other life forms, especially microbial life. In a spacecraft or in an artificial biosphere with its artificial and narrow ecology, we would be much more vulnerable to microbial life, which evolves exponentially more rapidly than humans do.

The two ancient branches of non-nucleated single cell life, the Archaea and the Bacteria, evolve about 500,000 times faster than does the human species, based on their respective reproductive

periods of 20 minutes and 20 years human. We have come to understand that there are about ten times more viruses than there are non-nucleated single-cell microbes. And viruses can replicate in one minute per progeny or 10 million times faster than humans and ten times faster than non-nucleated single-cell microbes. The reproductive time for viruses is one minute, for bacteria 20 minutes, and for humans 10,500,000 minutes. The survival of humans in space depends critically on the course of the evolution of the microbes that accompany humans into space. Viruses and microbes exist by the billions inside us, on our skin, in the air, in the water, in the soil and on every surface.

Evidence shows that these microbes evolve differently in the gravitation-free environment of space.

Evidence also shows that both the human innate and acquired immunity systems show a reduced ability to fight off microbes in gravitation-free living conditions.

It is known that latent retroviruses inside human genomes have been reactivated while humans are living in a gravitation-free environment. This could lead to diseases in humans.

Rapidly evolving viruses and microbes could kill all human life over any lengthy trip, leaving any spacecraft or biosphere to travel on without live humans aboard.

We evolved to live within earth's ecosystem. We almost certainly cannot live normal lives in a spacecraft, on another planet or within an artificial biosphere traveling through space.

The life forms that fare the best in changed or different conditions are those that reproduce the quickest and therefore evolve most rapidly. This means viruses and microbes have a huge advantage over multi-celled creatures like humans.

Free Worlds

The biologist and science fiction writer Isaac Asimov concluded, in his book Extraterrestrial Civilizations (1979) that the only possible way that humans or any other civilization anywhere in the

universe could achieve interstellar or intergalactic travel would be within what he called free worlds. We might call them artificial biospheres. Rather than living on the outer skin of a world, such as on earth, the beings would live inside a closed sphere simulating some of the characteristics of the outer world such as sunlight, day/night periods, rotation to simulate gravity and including a sample of the origin world's ecology of microbes, plants and animals. This would be an enormous undertaking. The free world would be set in motion in some direction in space and would travel forever away from its home planet, gradually losing all communication with its origin world. The humans aboard would live out their lives aboard the free world, with follow-on generations, if any, observing the passing scene.

It is a fanciful dream.

The Rama series of science fiction novels by the scientist and author Arthur C. Clarke scaled up the free world concept to convey exciting interstellar stories of former earthlings and many other beings who evolved on other planets, but these fiction stories ignore most of the scientific difficulties. In these stories, all the beings from different planets breathe the same air, eat the same foods, are comfortable in the same gravity field and have compatible microbes. None of these things would be true of beings evolved on different planets. Also, the Rama stories as fiction ignore most of the energy and propulsion issues that are an essential part of space travel.

Free worlds are not a realistic solution to human interstellar or intergalactic travel.

Communications With Other Beings In the Universe

If we can't travel outside our solar system, can we at least communicate with other technological civilizations that may exist

in other solar systems within our galaxy or beyond? We cannot. Let us see why.

Even the idea of humans chatting across the distances of our solar system is unrealistic. Two-way communications between earth and mars would take nine minutes and two-way communications with Neptune would take eight hours.

Our nearest neighbor star, Proxima Centauri, a red dwarf 4.2 light years distant from earth, has a planet called Proxima Centauri b located in the habitable zone of its star. Therefore, this planet could conceivably harbor life and even a technological civilization. If such a technological civilization happened to exist at the same time as earth's technological civilization, a vanishingly small possibility, we two civilizations could communicate with each other at the speed of light. Each civilization would have to wait 4.2 years for a message to be received and another 4.2 years for a return message. Two-way communications would take 8.4 years each time, a very sporadic form of communication.

Now imagine that we must search further than Proxima Centauri b for an intelligent and technological civilization. Just within our Milky Way galaxy such civilizations might be 100 light years distant, or 1,000 light years distant or 50,000 light years distant or more. If we could detect any signals from such civilizations, the messages would be from well in the past. We might send a message back but there might not be anyone still there to receive them after another 100, 1,000 or 50,000 years or more. Our nearest spiral galaxy, Andromeda, is 2.5 million light years distant; two-way communications would take 5.0 million years. If signals arrived from other galaxies, they would arrive from even further in the past, presumably from long-dead civilizations. Conversations with other technological civilizations is clearly a vanishingly remote possibility and the chances become smaller as distance increases.

Can we hear messages streaming through space sent, wittingly or unwittingly, like the radio and television signals we have sent out inadvertently?

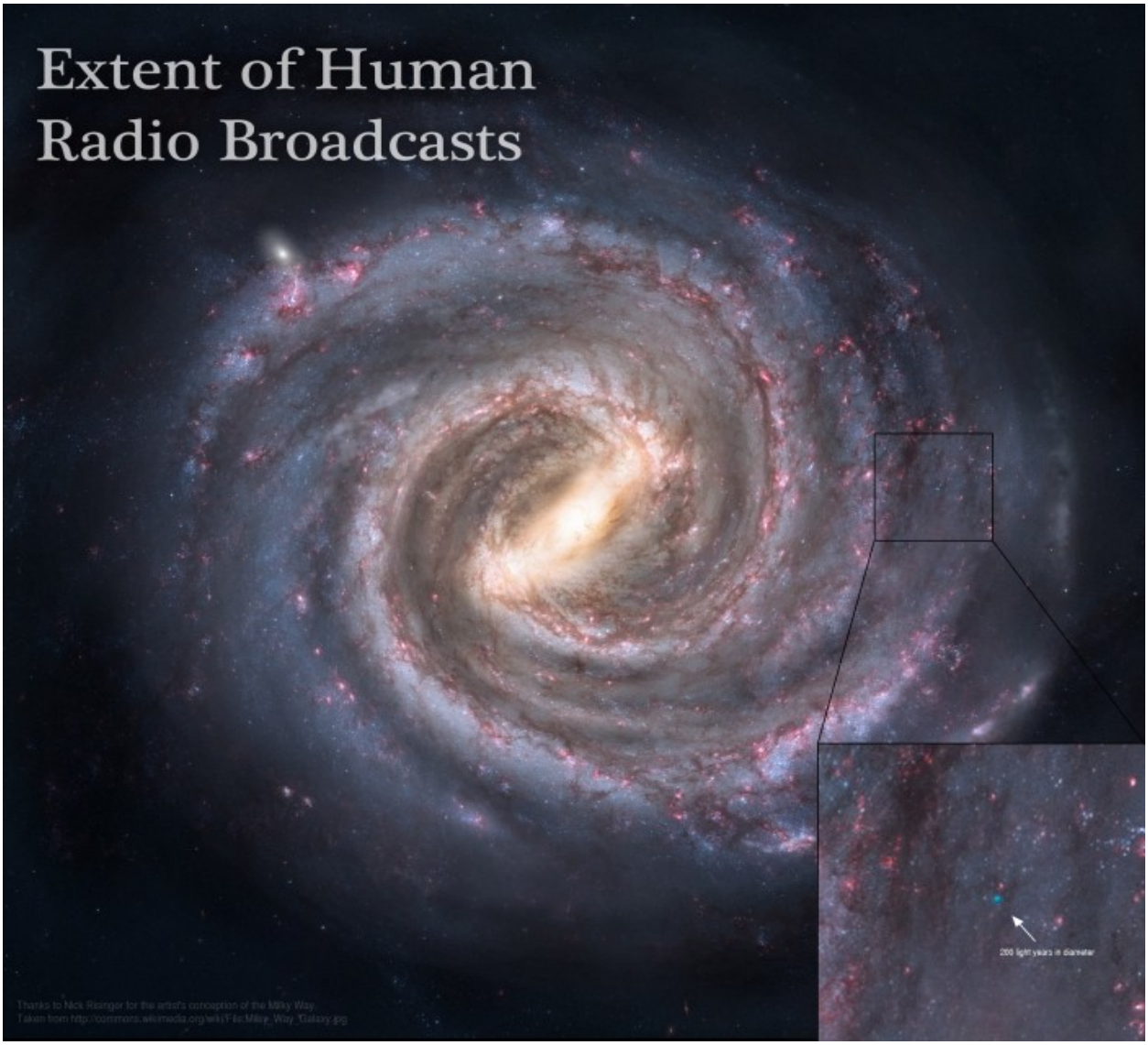
There is no simple formula for determining the detectability of electro-magnetic (EM) signals leaking into or deliberately sent into space by a technological civilization. Many factors affect the reach and detection of signals sent into space: distance, signal frequency, signal wattage, signal direction, obstructions, receiver size and other factors.

In a vacuum such as outer space EM signals travel at the speed of light, 9.46 x 10^12 kilometers per second. One light year is 9.46 x 10^12 x 60 seconds x 60 minutes x 24 hours x 365 days = 2.98 x 10^20 km.

EM signals spread out as they travel through space so that the power in watts declines rapidly on a per meter basis. Any detector therefore must be able to detect a smaller and smaller wattage signal as distance increases. Each time the distance doubles, the wattage per square meter declines by a factor of four. Twice the distance means one fourth of the signal wattage per square meter. No one can keep increasing the size of the receiver four times over and over again to capture the entire signal wattage. And at some distance the sent signal will decline so much per square meter that it will merge into the background EM noise of space and no longer be detectable.

Estimates of the distance over which earth radio signals could be detected range from a few light years—less than the 4.2 light years distance to our nearest neighbor star Proxima Centauri—to 100 light years where the signals might reach thousands of star systems. Neither of these public estimates come with the calculations that produced them, so that we will have to take them on faith. They reflect a difference of nearly a factor or 10. We might think of them as pessimistic and optimistic estimates.

Following is a visual to give a sense of scale of the distance that earth signals could have traveled in our Milky Way galaxy over the last roughly 100 years since radio signals began. At light speed the signals cannot have travelled very far from a galactic point of view.



Generally, a signal to noise ratio of 3:1 is deemed necessary for reliable signal detection. The Cosmic Microwave Background (CMB) of the universe is at a temperature of 2.725 Kelvin (-270.4 Celsius or -454.8 Fahrenheit), a relic of the Big Bang origin of the universe. The wattage of the CMB is 5.678 x 10^-8 watts per square meter per Kelvin raised to the power of four (Boltzmann's Constant) x 2.7^4 Kelvin with the CMB temperature raised to the power of four. The result is about 3 x 10^-6 watts per square meter or 0.000003 watts per square meter. A signal to noise ratio of 3:1 means that the signal must be 9 x 10^6 watts/m^2 to be detectable within the CMB noise of the universe.

But many objects in space such as stars, Quasars, supernova remnants, etc. emit large EM signals which makes the local background noise level far greater than the CMB background noise.

It is easy to see why signal detectability in deep space is unpredictable: signals spread and weaken at an alarming rate, the background noise varies enormously due to EM-emitting objects, and directed signals can only reach a very small wedge of space.

What this means is that the universe won’t allow different intelligent and technological civilizations located in different star systems even within our own galaxy to communicate with one another. Any intelligent and technological civilizations that exist or have existed or will exist are too far away from one another in both space and time to communicate with each other.

Whether this has some philosophical meaning is an open question. But astronomers have long pointed out that the rise of an intelligent and technological civilization, such as on earth, represents a way for the universe to observe and appreciate itself.

TECHNICAL APPENDIX

Units of Measure and Some Useful Formulas

Conversion of measurement units from metric system to English system units is often useful for communication purposes in the United States. Following are some useful conversions related to rocket and space travel data.

Kilograms (kg) = 2.2 pounds (lb); pounds (lb) = 0.454 kilograms (kg)

Newtons of force operating on any mass at earth's surface, such as a rocket:

Newton = kg x 9.8 or Newton = lb x 4.448

Kilometers(Km) = 0.621 miles (M); miles (M) = kilometers (km)/0.621

Meters(m) = 3.281 feet(ft); feet (ft) = 0.3048 meters (m)

Feet per mile equals 5,280

Seconds per hour equals 3,600

Meters per hour = meters per second x 3600 seconds

Miles per hour = meters per hour x 2.2356

Miles per hour = kilometers per hour x 0.621

One ton equals 1,000 Kg or 2,200 lb

c = speed of light = 300,000 km/s = 186,000 miles/s = 669,600,000 mph

= 5.866 x 10^12 miles per year = one light year

Temperature conversions between degrees Kelvin, Celsius and Fahrenheit.

K = C + 273.15 K = (F + 459.67)(5/9)

C = K – 273.15 F + K (9/5) – 459.67

C = (F – 32)(5/9) F = C (9/5) + 32

Some useful equations for our purposes are the following.

Earth's gravity is an accelerative force; on earth at sea level that rate is g = 9.8 m/s^2 or 32 ft/s^2. Gravity is a constant attractive force.

Here is how gravity affects an object in free fall, using the earth's gravity at sea level as an example where gravity = 9.8 meters/second^2.

t (s) g (m/s^2) velocity (m/s) distance (m) fall time, given distance (m)

given	given	9.8 x t	½ 9.8 x t^2	t = [m/(1/2 x 9.8)]^(1/2)
1	9.8	9.8	4.9	1
2	9.8	19.6	19.6	2
3	9.8	29.4	44.1	3
4	9.8	39.2	78.4	4
5	9.8	49.0	122.5	5

Gravity declines slowly away from the surface of a planet.

G = G(M/r^2)

g = the strength of gravity (m/s^2)

G = the gravitational constant, 6.674 x 10^-11 Newtons (m/kg)^2

M = the mass of the planet or object (earth mass = 5.972 X 10^24 kg)

r = the radius of the planet or object (earth = 6,378,000 meters)

g at the earth's surface = 6.674 x 10^-11 (5.972 x 10^24/6,378,000^2)

= 9.8 m/s^2

Gravity at some distance d from the surface of the planet is expressed by the equation g(d) = G[M/(r+d)^2] or GM/(r+d)^2 = (3.99 x 10^14)/(6,378,000 +r)^2.

At the distance of the International Space Station from the surface of the earth at 250 miles or 403 kilometers (403,000 meters), gravity equals 8.67 m/s^2 or 88% of the gravity felt at the surface of the earth. The occupants of the ISS don't feel this gravity because the ISS is in free fall toward the earth at all times but is held at a virtually constant distance from the earth because it is traveling around the earth at about 17,500 miles per hour.

At 1,000,000 meters from the earth's surface (1,000 kilometers or 621 miles), earth's gravity is at 7.32 m/s^2 or 75% of the gravity at earth's surface.

Earth's gravity never reaches zero but it can be ignored at great distances from earth.

<u>Equations</u>

F = ma = thrust

A basic equation for rocket analysis is force or thrust equals mass times acceleration. In metric units mass (kilograms) x acceleration (meters per second squared) equals force (kg m/s^2). The unit of force is called a Newton. One Newton of force is required to accelerate one kg of mass at the rate of one meter per second squared or one meter per second per second. Mass is synonymous with inertia. Even when no appreciable gravitational force is present, such as in deep space, inertia is

present. Each kilogram of mass requires one Newton of force to move it one meter even in deep space.

Thrust is usually determined by testing engines on stationary ground stations that measure the force generated by the engine. Thrust is measured in units of Newtons of force, which equals kg m/s^2, or momentum per second. Thrust is equal to the mass burn rate (kg/s) times the exhaust velocity (m/s). The exhaust velocity Ve (m/s) is equal to the Isp (s) times earth gravity at sea level or g (9.8 m/s^2).

Impulse is thrust times some number of seconds of rocket burn time. Thus, T (kg m/s^2) x t (s) = impulse (kg m/s^2 s). This quantity can be designated Ns just as thrust can be designated N. Later we will encounter the important ratio Ns/N. As an example of impulse, the Command/Service Module rocket of Apollo 11 had 750 seconds of burn time available in fuel. The rocket's thrust in Newtons times 750 seconds gave the total impulse available. When the rocket was fired to leave the moon's orbit and return to earth the seconds of burn times the thrust gave the impulse of that burn.

Momentum, p = mv

Momentum is defined as mass times velocity. Mass (kg) x velocity (m/s) equals momentum (kg m/s). Every momentum in one direction causes an equal reaction momentum in the opposite direction. By throwing some mass in one direction we can propel ourselves in the opposite direction. We can create momentum by throwing a large mass at a slow speed or by throwing a small mass at a high speed. Thus, 10 kg thrown at 3 meters per second equals the momentum of 30 kg m/s. And 1 kg thrown at 30 meters per second equals the same momentum. In rocket research the goal is to throw as small a mass as possible with as great a velocity as possible. This explains the central importance of exhaust velocity.

Mass Flow Rate, R (kg/s)

During rocket engine testing the mass flow rate of the fuel is determined by monitoring the amount of fuel used and the number of seconds of burn time.

Exhaust Velocity Ve (m/s)

Knowing the thrust and the mass burn rate, we can calculate the rocket nozzle exit velocity Ve (m/s) as thrust (kg m/s^2) / mass burn rate (kg/s).

Specific Impulse Isp (s)

Analogous to miles per gallon for gasoline automobiles, the specific impulse is a measure of the efficiency of a rocket engine's use of fuel. The specific impulse is designated Isp. It is calculated as impulse (Ns) divided by thrust (N) resulting in units of seconds. Isp is also equal to Ve (m/s) / sea level gravity g (9.8 m/s^2), also resulting in units of seconds. Recall that Ve = thrust/mass burn rate. The Isp of each engine gives a common unit of comparison of efficiency. The higher the Isp value the more efficient the engine in generating the greatest amount of thrust with the least amount of propellent.

The Rocket Equation Outside a Gravity Field

This brings us to the Rocket Equation

$$M_i \,/\, M_f = e^{(\frac{delta\,V}{Ve})}$$

where M_i is the initial mass (kg)

Mf is the final mass (kg)

e is the transcendental number 2.718...

delta V is the change in velocity that we desire (m/s)

Ve is the exhaust velocity of the rocket engine (m/s)

The Rocket Equation is concerned with momentum. The momentum elements of the equation are delta V and Ve, with delta V (change in ship velocity) going in one direction and Ve (rocket exhaust velocity) going in the opposite direction.

The outcome of the equation tells us the multiple of the mass of the payload we will need in fuel to be able to reach the delta V we have chosen.

If we are seeking to place our payload in an earth orbit, and we know that we must achieve a velocity of 17,500 mph, equal to 7.83 km/s, and we know that the Ve of our rocket is 3.05 km/s, then

$$M_i \,/\, M_f = e^{(\frac{7.83}{3.05})} = e^{2.567} = 13.$$

You can understand why rockets are so large compared to their payload.

If we want to send our payload beyond earth we will have to achieve a velocity of 25,000 mph or 11.2 km/s. The Rocket Equation gives this result.

$$M_i \,/\, M_f = e^{(\frac{11.2}{3.05})} = e^{23.67} = ¿\ 39.$$

This requires a much bigger load of fuel.

Both these objectives, orbit and beyond earth, require stages of rockets as boosters that can provide massive thrust, burn their fuel and then be released. The Apollo mission to the moon required three booster rockets to get the moon module on its way.

If we wanted to send a ship to Mars, giving it an initial velocity of 50,000 mph or 22.4 km/s, the results of the Rocket Equation look like this.

$$M_i \,/\, M_f = e^{(\frac{22.4}{3.05})} = 1{,}547.$$

This is an impossible fuel requirement except perhaps for very small payloads.

What about reaching 100,000 mph or 44.8 km/s for our Mars ship?

$$M_i \,/\, M_f = e^{\left(\frac{44.8}{3.05}\right)} = 2{,}394{,}116.$$

Taking a different approach, what if we could increase the exhaust velocity of our rocket. Some think that chemical rocket exhaust velocity might be increased to 5 m/s.

$$M_i \,/\, M_f = e^{\left(\frac{22.5}{5}\right)} = 90 \text{ and } M_i \,/\, M_f = e^{\left(\frac{44.8}{5}\right)} = 7{,}785.$$

Huge improvements but these are still daunting numbers.

So far, rocket engines for delivering large payloads rely on chemical fuels and chemical reactions. There has long been a search for other kinds of fuel with increased exhaust velocity. Unfortunately, other propellants all have lower thrust than chemical propellants. Thrust, you recall, is in units of kg m/s^2. The alternative fuels have a higher m/s velocity but they have a lower kg/s flow rate. High momentum, kg m/s, requires both. With a lower kg/s value, thrust is lower. All the alternatives so far are used with small payloads and slow acceleration rates. They work in outer space with small long-range space probes but they are unsuitable for human-crewed spacecraft or large craft of any kind. Recall that the larger the spaceship, the greater the Newtons of force it takes to accelerate it or to decelerate the ship as it approaches its destination.

At near light speeds, the Rocket Equation takes a different form. The relativistic Rocket Equation looks like this.

$$M_i \,/\, M_f = \left[\frac{1+\frac{delta\ V}{c}}{1-\frac{delta\ V}{c}}\right]^{\left(\frac{c}{2\ Ve}\right)}$$

where: delta V = the desired change in velocity

c = the speed of light and Ve = the rocket exhaust velocity.

The Rocket Equation Inside a Gravity Field

$$M_i / M_f = e^{(\frac{delta\ V+¿}{Ve})}$$

where g = the force of the gravity field (m/s^2)

and t = rocket engine burn time (s)

The Rocket Equation and Delta V

Since the Rocket Equation includes the term delta V, we can use the equation to find the velocity of the rocket.

Outside a gravity field, the equation looks like this

delta V = Ve ln (Mi/Mf).

Inside a gravity field, the equation looks like this

delta V = Ve ln (Mi/Mf) – gt were gt is the force of the gravity field (m/s^2) times the rocket burn time in seconds.

Alternative Velocity Calculation Outside a Gravity Field

With constant thrust and increasing acceleration as fuel is burned, the velocity of the rocket is given by the following equation.

V(t) = -Ve ln[1-(Rt/Mi) = -Ve times a number

where V(t) = the velocity of the rocket at time t (m/s)

Ve = the exhaust velocity (m/s)

R = the mass burn rate of fuel (kg/s)

t = time elapsed in seconds (s)

Mi = the initial mass of the rocket (kg)

For any given delta V, t = (Mi/R)(1-e^(delta V/Ve).

If the rocket is throttled back as fuel is burned to keep acceleration constant, then

V(t) = net thrust times t/Mt

where V(t) = the velocity of the rocket at time t (m/s)

Net thrust = total thrust less any offset for gravitational force

T = time elapsed in seconds (s)

Mt = the mass of the ship when t seconds have elapsed

In space, away from any significant gravitational influences, net thrust = total thrust.

Alternative Velocity Calculation Inside a Gravity Field

V(t) = (-Ve + gt) ln [1 – (Rt/Mi)]

where g is the force of the gravity field (m/s^2).

The Rocket Equation and Travel Time Outside a Gravity Field

If you maintain a constant thrust your acceleration will increase as fuel is burned. An equation to determine your travel time to reach a given velocity goal is given by Richard Feynman.

t = (Mo/R)(1-e^(-Vgoal/Ve)

where t = the travel time in seconds (s)

Mo = the original mass of the ship (kg)

R = the mass burn or fuel use rate (kg/s)

e = 2.718

Vgoal = the velocity goal (m/s)

Ve = the exhaust velocity (m/s)

This situation is most applicable where humans are not aboard the ship since they would not tolerate long-term periods of acceleration at multiples of earth’s gravity.

When humans are on board the ship and lengthy trips are expected, it makes more sense to throttle back the thrust after reaching acceleration at earth gravity level to maintain an earth-level gravity aboard the ship. In this case the time to reach a given velocity goal will take longer than with constant thrust. To achieve a given delta V under constant acceleration such as earth gravity of one g, the calculation is t = delta V/acceleration with t in seconds, delta V in m/s and acceleration in m/s^2. For example, if we wanted to achieve 30% of light speed while accelerating at 9.8 m/s^2, the calculation is

t = .3c/9.8 = .3(300,000,000)/9.8 = 9,183,674 seconds or 107 days.

Acceleration Outside and Inside a Gravity Field

Outside a gravity field, acceleration may be calculated by

$$a(t) = (N/Mi)-Rt$$

where a(t) = acceleration at time t (m/s^2)

N = Newtons of force (kg m/s^2)

Mi = initial rocket mass (kg)

R = rocket engine mass burn rate (kg/s)

t = rocket engine burn time (s)

Inside a gravity field, acceleration may be calculated by

$$a(t) = (N – Rgt)/(Mi – Rt)$$

where g = the force of the gravity field (m/s^2).

Delta-V and burn time in seconds Outside a Gravity Field

Delta-V refers to our wish to change the rocket’s velocity by some amount called delta-V.

The formula is: delta V (m/s) = thrust (mkg/s^2) x burn time (s) / ship mass (kg).

Since thrust x burn time = impulse, delta V = impulse/ship mass.

If we twist the equation around, we get

burn time = delta-V/thrust/ship mass.

And ship mass = burn time/delta V x thrust.

To illustrate we will look at the Apollo 11 rocket burn to free the Command and Service Module (CMS) from the grip of the moon's gravity while they orbited the moon. In orbit the CMS was traveling at 1,624 m/s (3,650 mph). The escape velocity of the moon is 2,380 m/s (5,349 mph). The CMS wanted to increase its velocity by 1,001 m/s (2,250 mph) to a new velocity of 2,625 m/s (5,855 mph). The CMS rocket had a thrust of 91,190 Newtons of force and a mass before the rocket burn of 13,483 kg. The seconds of burn required equals delta-V/(thrust/rocket mass) or 1,001/(91,190/13,483) = 1,001/6.763 = 148 seconds. As a check on our formula for ship mass, ship mass = 148/1001 x 91190 = 13,483 kg.

Incidentally, when the CMS left earth orbit for the moon it had enough fuel aboard to burn for 750 seconds or 12.5 minutes. This means that the amount of fuel aboard the CMS was 750 times the mass burn rate in kg/s. The mass burn rate of the CMS was thrust/Ve or 91,190/(9.8 X 314.5) = 29.6 kg/s. The burn rate per second times 750 seconds is 22,190 kg of fuel aboard at the start of its trip.

If we maintain a constant acceleration such as the equivalent of earth's gravity of 9.8 m/s^2, the rocket burn time required to reach a given delta V is simply delta V / the acceleration rate. E.g., 100,000/9.8 = 10,204 seconds or 2.83 hours.

About the Author

John V. Peters was born in Wenatchee. WA in 1943 and grew up in Manson. He has a bachelor's degree in economics from Grove City College, PA and has taken some master's degree classes in history from Seattle University. He spent two years in the Army (8th Special Forces Group, Ft. Gulick, Panama), worked two years for Old National Bank in Pasco and Kennewick, WA, six years in the budget office of the Seattle School District and 20 years in the finance department of the Boeing Company in Seattle. He undertook this research for his own edification and wishes to share the results.